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MELVILLE T. COOK, Editor

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THE NUTRITIVE VALUES OF SOME FORAGE CROPS OF PUERTO RICO [1, 2, 3]

1. Grasses

By J. H. AXTMAYER, C. F. ASENJO and D. H. COOK,
of the Department of Chemistry, School of Tropical Medicine, San Juan, P. R.

INTRODUCTION

The importance of the knowledge of the feeding value of forage crops in relation to the modern livestock and dairy industries is recognized.

Metabolic experiments carried out with lambs have proved to be an acceptable and practical method of determining nutritional indexes of feeds, such as the biological value, coefficient of apparent digestibility, etc., these serving to give the relative nutritive values of different forage crops when fed to ruminants.

Since no work of this kind has been undertaken before in Puerto Rico, we have had up to the present time no exact knowledge concerning the nutritive values of the different pastures used in our dairy and livestock industry.

The data presented here has been collected from experiments carried out during the years 1936 and 1937. We have tried to obtain information (similar to that collected in studies on forage crops in the United States) concerning the nutritive values of those pastures most commonly used on our Island, but in no way should this initial investigation be taken as a final dictum on the matter. In addition to the work which has been done to determine the nutritional indexes of the different grasses studied, we have also tried to obtain information regarding the influence such factors as the stage of maturity at the time of cutting, the cutting and the kind of fertilizer used, may have on the nutritive values of these grasses.

[1] Cooperative project between the Agricultural Experiment Station of the University of Puerto Rico and the School of Tropical Medicine.

[2] Field work was conducted by the Experiment Station at Río Piedras.

[3] Study made possible from grant-in-aid of the Bankhead Jones Act of U. S. A. Congress 1936.

These factors are of enough importance to be the subject of a special investigation. Therefore, justification for presenting the present study lies in the hope that the data given here shall serve to indicate the problems to be solved in a systematic study of the nutritive indexes of the forage crops of our Island.

Review of the Literature

Although literature on the present subject is non-existent in Puerto Rico, it is so extensive in the States that it seems unnecessary for us to present more than a review of those studies from which we have taken our method. Sotola points out that the most accurate method of evaluating proteins at the present time appears to be that employed by Thomas and later modified by Mitchell (1). Mitchell performed a rigorous and extensive investigation of his method and came to the conclusion that it possessed a high degree of accuracy. It will be interesting to note that Mitchell used white rats as experimental animals. The method followed by Sotola (2) in his investigation on the biological value of the forage crops of the United States is similar to that recommended by Mitchell, being modified only in that Sotola used sheep instead of rats. The advisability of using sheep is clear, as results obtained in nutritive experiments with these animals have been shown to apply to cattle (3), and they are easier to work with.

The methods we followed in the determination of apparent coefficients of digestibility were the ones used by Sotola (4).

Material and Methods

The animals used in our experiment were native sheep whose ages ranged from six to eighteen months when purchased. We searched the Island in the hope of finding a pure breed of sheep, but could not find a single farm where the breeding or care of sheep were carried out under controlled conditions. The animals had been allowed to roam about the farms and could not be used during the first two or three weeks after they were brought to the laboratory because they were practically unmanageable.

The grasses studied were grown at the Experiment Station Farm of the University of Puerto Rico at Río Piedras. A field of approximately 2 acres was divided into seventy-two 1/40 acre plots, each treatment of the soil being replicated twelve times. One half of the replication was fertilized with a mixture of 400 pounds of

ammonium sulphate and 200 pounds of double superphosphate per acre, and the other half was fertilized with 400 pounds of ammonium sulphate alone per acre.

The stages of maturation at which these grasses were cut were just before or during the flowering periods.

The cutting was done early in the morning, the grasses being chopped into pieces ranging from 2 to 4 inches in length, put into jute bags and sent to us by truck, arriving usually at about 8 or 9 o'clock in the morning.

The detailed field conditions under which the grasses were grown are given in table A.

Experimental

Metabolism cages, 3½ feet long, 2 feet wide, and 3 feet high, similar to those used by Sotola (4) were constructed at the School shop. Each cage was provided with a double bottom for the collection of the urine and feces separately.

The animals, before beginning an experimental period, were kept during a preliminary period of 10 days on the ration to be tested. At the termination of this preliminary period, the animals were placed in the metabolism cages and the collection of the data for the experiment was begun. Each experiment lasted ten days.

The following data were collected during these ten-day experimental periods: 1. Initial and final weights of the animals at the start and the end of the experimental periods. 2. Weights of the feed consumed per day. 3. Weights of the feed refused per day. 4. Weights of the feces eliminated per day. 5. Volumes of the water consumed per day. 6. Volumes of the urine eliminated per day.

These data were collected practically at the same time every day, from 9 to 10 a. m., and aliquot samples of the feeds given, the refuse left, and the feces and urine eliminated, were taken for analysis.

All the solid samples collected were dried in an air oven at 100°C. The composite aliquot samples of the feces and urine were kept in the ice box. Xylol was added to the urine as preservative. The samples of the grasses were kept in paper bags after having been dried. All the solid samples were ground in a Willy mill at the end of each experimental period; the powder obtained was mixed, and large enough portions of it were put into amber bottles provided with tight stoppers to be preserved for analysis. All the analyses reported in this study have been performed according to the methods of the Association of Official Agricultural Chemists. In the case of the nitrogen determinations, we used a solution consisting of ten

TABLE A

FIELD CONDITIONS OF THE GRASSES USED IN THE TRIALS PERFORMED

Trial No.	Common name of the grass	Scientific name of the grass	Fertilized with*	Dates on which samples were collected	Cutting	Stage of maturation when cut	Rain in inches
2	Corn fodder	*Zea Mays L.*	N and P	August 27 to Sept. 5, 1936	1st	In flower	8.37 to 8.92
4	Elephant grass	*Pennisetum purpureum* Schum.	N	Sept. 22 to Oct. 2/36	1st	Just before flowering	8.92 to 6.85
13	Elephant grass	*Pennisetum purpureum* Schum.	N	Jan. 6 to Jan. 16/37	1st	Just before flowering	17.39
6	Elephant grass	*Pennisetum purpureum* Schum.	N and P	Oct. 13 to Oct. 23/36	1st	Just before flowering	6.85
11	Elephant grass	*Pennisetum purpureum* Schum.	N	Dec. 16 to Dec. 26/36	1st	Just before flowering	8.61
5	Guinea grass	*Panicum maximum* Jacq.	N	Oct. 13 to Oct. 23/36	1st	In flower	6.85
12	Guinea grass	*Panicum maximum* Jacq.	N	Dec. 16 to Dec. 26/36	1st	In flower	8.61
7	Guinea grass	*Panicum maximum* Jacq.	N and P	Nov. 4 to Nov. 14/36	1st	In flower	2.38
14	Guinea grass	*Panicum maximum* Jacq.	N and P	Jan. 6 to Jan. 16/37	1st	In flower	17.39
8	Malojillo or Para grass	*Panicum barbinode* Trin.	N	Nov. 4 to Nov. 14/36	1st	Just before flowering	2.38
27	Malojillo or Para grass	*Panicum barbinode* Trin.	N	April 28 to May 8/37	2nd	In flower	1.54
20	Malojillo or Para grass	*Panicum barbinode* Trin.	N and P	March 15 to 25/37	2nd	In flower	0.45
25	Malojillo or Para grass	*Panicum barbinode* Trin.	N and P	April 17 to 27/37	2nd	In flower	1.54
9	Guatemala grass	*Tripsacum laxum* Nash.	N	Nov. 25 to Dec. 5/36	1st	Just before flowering	2.38
23	Guatemala grass	*Tripsacum laxum* Nash.	N	March 26 to April 5/37	2nd	Just before flowering	0.47 to 1.54
10	Guatemala grass	*Tripsacum laxum* Nash.	N and P	Nov. 25 to Dec. 5/36	1st	Just before flowering	2.38 to 8.61
22	Guatemala grass	*Tripsacum laxum* Nash.	N and P	March 26 to April 5/37	2nd	Just before flowering	0.47 to 1.54
24	Yaragua or molasses grass	*Melinis minutiflora* Beuv.	N	April 6 to April 16/37	2nd	Just before flowering	1.54
17	Yaragua or molasses grass	*Melinis minutiflora* Beuv.	N and P	Feb. 20 to March 2/37	2nd	Just before flowering	1.08 to 0.47
26	Yaragua or molasses grass	*Melinis minutiflora* Beuv.	N and P	April 17 to April 27/37	2nd	Just before flowering	1.54

*N means those fertilized with ammonium sulphate alone. N and P means those fertilized with ammonium sulphate and superphosphate.

parts of a saturated solution of methyl red in 50 per cent alcohol and one part of a 0.25 per cent methylene blue solution in water as an indicator to titrate the standard acid in which the ammonia was collected against the standard base. A freshly prepared solution was used whenever titrations were performed. This indicator mixture has the advantage of giving a very sharp end point, changing from violet on the acid side to green on the alkaline side.

An artificial ration having the following composition was given to the animals during the trials performed for determining the minimum protein required for maintenance:

Para grass straw (no leaves)	10.00 per cent
Sugar	21.43 per cent
Starch	21.43 per cent
Cellu flour	43.90 per cent
Bone meal	2.00 per cent
Oil	1.24 per cent

Group A and Group B of our animals became used in this diet after a short time and ate an average of about 400 grams of it per day. The animals of Group D and Group E never became used to it, preferring rather to starve. Due to this, we ran only four trials on this low protein diet; three with animals in Group A and one with animals in Group B. We have calculated the body nitrogen in the feces per gram of dry matter ingested and the body nitrogen in the urine per kilogram of body weight from the data obtained from these trials. The average value obtained from these four trials was applied to all our animals.

Existing data indicates that the body nitrogen in the feces per gram of the dry matter ingested and the body nitrogen in the urine per kilogram of the body weight for sheep receiving a low nitrogen ration is quite uniform. We include the results obtained by other investigators as well as by ourselves for the low protein trials, in table 3. These results are quite close if we consider the different breeds of animals used.

Results

Table no. 1 records the percentage content of nitrogen in the feed consumed, the refuse left, and the feces and urine eliminated. These values are later used in the determination of the biological values of the grasses.

Table no. 2 gives the data gathered during the four ten-day metabolism experiments in which the nearly nitrogen-free rations were fed. The average values obtained for the body nitrogen in

the feces per gram of dry matter ingested and the body nitrogen in the urine per kilogram of body weight are 0.043 grams and 0.526 grams of nitrogen respectively. We have applied these average values in computing all our calculations for the biological values of the proteins.

Table 3 reports the values for body nitrogen in the feces per gram of dry matter ingested and body nitrogen in the urine per kilogram of body weight obtained by other investigators as well as by us.

Table 4 gives a summary of the metabolism experiments upon which the determinations of the biological values of the protein in the grasses are based. "Body Nitrogen Feces" is obtained by multiplying the weight of the total dry feed intake by the body nitrogen in feces per gram of dry matter ingested; while the "Body Nitrogen in Urine" is obtained by multiplying the average body weight of the animal in kilograms by the body nitrogen in urine per kilogram of body weight. The percentage of the total protein absorbed through the intestine and retained in the body is called the "Biological Value" of the protein. This value is computed from the following equation:

$$\text{Biological value} = \frac{100 \text{ Food N} - (\text{Total N in feces} - \text{Body N in feces}) - (\text{Total N in urine} - \text{Body N in urin}}{\text{Food N} - (\text{Total N in feces-Body N in feces})}$$

$$100 \frac{\text{Food N retained}}{\text{Food N absorbed}}$$

Table 5 contains all the proximate analyses of the offered and refused portions of the rations used in the different experiments. These analyses are all reported on a dry basis. Protein throughout this work is understood to be the nitrogen value multiplied by the factor 6.25.

Table 6 gives the proximate analyses of the feces eliminated during the different trials. These analyses are also given on a dry basis.

The coefficients of apparent digestibilty are given in table 7. By this coefficient we mean the percentage of the substances in the feed eaten that is absorbed in the intestinal tract. Coefficients of apparent digestibility of dry matter, fat, carbohydrate, ash and organic matter have been calculated. These coefficients are computed with the following equation:

$$\text{Coefficient of apparent digestibility} = \frac{100 \text{ Substance in the feed fed} - \text{Substance in the feces eliminated}}{\text{Substance in the feed fed}}$$

Table 8 gives the digestible nutrient in 100 pounds of feedstuff on the wet basis in addition to the nutritive ratio of each ration (5). The digestible fats, carbohydrates and proteins are obtained by multiplying the total amount of each nutrient in 100 pounds of the feed by the apparent coefficient of digestibility for that nutrient, as given in table 7.

The second term of the nutritive ratio is calculated by means of the following formula:

$$\text{The second term of the nutritive ratio} = \frac{(\text{Digestible fat} \times \text{heat equivalent} = 2.25) + \text{Digestible carbohydrates}}{\text{Digestible crude protein}}$$

A feed or ration having much crude protein in proportion to the carbohydrate and fat combined is said to have a narrow nutritive ratio. If the opposite is true it is said to have a wide nutritive ratio.

Table 9 gives the proximate and ash analyses of the grasses investigated, these determinations being reported on the wet basis, while table 10 contains the same data after having been calculated on the dry basis.

Table 11 is a summary of all the coefficients calculated from the data obtained in this investigation.

The vitamin A activity determinations are recorded in table 12.

Discussion

The biological values of the grasses studied do not show great differences if we are to judge these from the results obtained and indicated in the tables.

The proteins of all these grasses seem to be utilized by the lambs with the same efficiency. A significant low result was obtained in Trial No. 6 when elephant grass of the first cutting, fertilized with nitrogen and phosphorus, was fed. The biological value computed for this grass is 69. In the other three trials performed with this grass, much higher results were obtained, viz., 81, 80 and 80; nevertheless, these four samples of elephant grass recorded the lowest biological values obtained in all of the grasses investigated. Two rations of the grass fed to the animals had been fertilized with nitrogen and phosphorus. All of them were from the first cuttings. On the other hand, the malojillo or Para grass has given the highest biological value, viz., 88, 97, 89 and 91. The first value corresponds to a grass from a first cutting fertilized with nitrogen only; the other three were grasses from the second cuttings, one fertilized with nitrogen only and the other two with nitrogen and phosphorus.

The other four grasses investigated gave values which fall within the range of those obtained for elephant and Para grasses.

The data obtained in these experiments seem to indicate that the biological value is not greatly influenced by the addition of phosphorus as fertilizer or by the cutting. We can conclude, on the basis of the results obtained, that the quality of the protein is inherent in the type of grass, since very similar results were obtained for the same grass in first or second cuttings, and when fertilized with nitrogen or nitrogen and phosphorus.

The trials in which Guatemala grass was fed yielded the highest values obtained for the average coefficients of apparent digestibility for the dry matter, the lowest values obtained corresponded to the Yaragua grass. In the case of the coefficients for crude protein, Para grass trials of first cutting grass recorded the highest value, while the three trials with Yaragua grass yielded the lowest results. The other three trials with Para grass of second cuttings were significantly low, running second to the Yaragua grass trial results. The results obtained with second cutting Para grass seem to indicate that the cuttings exert a significant influence upon the digestibility of the protein. It is interesting to note that all the samples of Yaragua grass tested were from second cuttings and that they contained the least digestible proteins of all the grasses studied. Whether this low index of digestibility is inherent to the grass or is due to the cutting cannot be stated with certainty, since only second cuttings of this grass were tested. This grass also recorded very low coefficients of apparent digestibility for ash. These low values may be due either to the fact that the mineral constituents are not as readily absorbed as in the case of the other grasses or to a lack of palatability of the Yaragua grass, which is the least palatable of all the grasses investigated. Consequently, the animals consumed less of this grass during the ten-day experimental periods than the average weights eaten during similar trials with the other grasses. The total intake of mineral matter then was not enough to supply the output. This second explanation seems to us to be the most plausible one. Palatability is unquestionably an important factor which also has to be considered, as it may greatly influence the nutritive indexes. It is quite apparent that the addition of phosphorus to the fertilizer does not seem to influence the apparent coefficients of digestibility to any great extent.

The nutritive ratios show wide variations. Yaragua grass gives a very wide nutritive ratio, as is to be expected, for it has a low protein coefficient of apparent digestibility. As a matter of fact,

the nutritive ratio obtained in Trial No. 24 for this grass is extremely wide due to the very low digestibility of the protein. The values for the other two trials with this grass, although wide, are within reasonable limits. The nutritive ratio for corn fodder shows the narrowest value of all. The other grasses give values a little wider than those obtained for fresh green roughage in the United States.

Second cutting grasses recorded nutritive ratios which were always wider than those of the first cutting grasses. This is most probably due to the fact that the second cutting grasses yield, on a wet basis, lower percentages of protein than first cutting grasses. The fat and carbohydrate contents of second cutting grasses are higher than those for the first cutting grasses.

The chemical analyses of the grasses show some interesting facts. The protein contents vary, when the analyses are calculated on the dry basis, from 9.50 per cent for corn fodder, first cutting fertilized with nitrogen and prosphorus, to 2.61 per cent for Yaragua grass, second cutting, fertilized with nitrogen only. All second cutting grasses show lower protein contents than first cutting grasses. The same is true of the fat The nitrogen-free extract, on the contrary, is always greater in second cutting than in first cutting grasses. Guinea grass shows a higher calcium content than the other grasses; Guatemala grass gives the lowest result. Yaragua grass shows the highest per cent of crude fiber. The phosphorus contents of these grasses seem to be quite constant. The addition of phosphorus to the fertilizer has not shown any appreciable effect on the phosphorus contents of the grasses.

No conclusive results can be obtained from these series of experiments. We have considered only the two factors, fertilizer and cutting, in this discussion, but there is still a third which we have not touched on. This factor is the stage of maturity at which the grasses were cut and eaten by the experimental animals. As will be seen from the table of field conditions presented under the heading "Materials and Methods" at the beginning of this paper, some of the grasses sent to us were cut before the flowering stage and others, during the flowering stage. The stage of maturity at which the grasses are cut affects their nutritive values; therefore, this factor has to be studied separately, and will be, in further experiments.

Summary

1. Twenty metabolic experiments with grasses cut at different periods, between August 1936 and May 1937, are reported.

2. The biological values were determined for these grasses; the

highest recorded values belonging to Para grass and the lowest values to elephant grass.

3. The coefficients of apparent digestibility for Yaragua and malojillo grasses of second cutting are quite low.

4. All the grasses tend to give wide nutritive ratios, but Yaragua and malojillo, second cutting grasses, give exceptionally wide ones.

5. Yaragua grasses show a higher fiber content than any of the other grasses investigated.

6. Guinea grass yields, on analysis, significantly high values for calcium; Guatemala grass yielding the lowest values for this element in all the grasses studied.

7. First cuttings of grasses usually yield higher percentages of protein than second cuttings. The same is true of the fat. The nitrogen-free extract, on the contrary, is lower in first cutting than in second cutting grasses.

8. The addition of phosphorus to the fertilizer does not seem to influence to any great extent the nutritive indexes of the grasses studied.

9. The vitamin A activity of the leaves of the grasses has been determined.

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TABLE 1

PER CENT NITROGEN IN FEED FED, REFUSE LEFT, FECES & URINE

(FEED, REFUSE AND FECES ANALYSES, PER CENT ON DRY BASIS.)

(URINE ANALYSES, PER CENT BY VOLUME.)

Trial No.	Ration	Nitrogen in Feed Fed %	Nitrogen in Refuse Left %	Animal	Nitrogen in Feces %	Nitrogen in Urine %
1.....	Low protein diet Formula I..	0.17	.....	1A....	0.69	0.14
				2A....	0.99	0.18
				3A....	0.91	0.20
2.....	Corn fodder (N and P) first.	1.52	1.30	1A....	1.51	0.24
				2A....	1.47	0.30
				3A....	1.38	0.28
3.....	Low protein diet Formula I..	0.23	.....	1B....	0.84	0.60
				2B....	0.92	0.37
				3B....	1.05	0.17
4.....	Elephant grass (N only) first.	0.81	0.34	1A....	1.06	0.26
				2A....	1.07	0.34
				3A....	1.03	0.23
13.....	Elephant grass (N only) first..	0.87	0.40	1B....	1.01	0.18
6.....	Elephant grass (N and P)... first	0.72	0.37	1A....	1.09	0.28
				2A....	1.17	0.43
				3A....	1.07	0.32
11.....	Elephant grass (N and P)... first	1.20	0.52	1B....	1.14	0.13
				2B....	1.19	0.13
				3B....	1.08	0.15
5.....	Guinea grass (N only)..... first	0.94	0.62	1B....	0.95	0.35
				2B....	0.92	0.47
				3B....	0.93	0.42
12.....	Guinea grass (N only)..... first	0.87	0.40	1A....	0.97	0.23
				2A....	1.08	0.27
				3A....	1.08	0.30
7.....	Guinea grass (N and P)..... first	0.96	0.73	1B....	0.99	0.35
				2B....	0.99	0.36
				3B....	0.96	0.45
14.....	Guinea grass (N and P)..... first	0.83	0.46	1A....	1.01	0.18
				2A....	1.02	0.34
				3A....	0.99	0.25
8.....	Malojillo grass (N only)..... first cutting	1.06	0.52	1A....	1.28	0.21
				2A....	1.37	0.29
				3A....	1.21	0.24
27.....	Malojillo grass (N only)..... second cutting	0.50	0.38	1A....	1.02	0.48
				2A....	0.89	0.52
				3A....	0.81	0.38
20.....	Malojillo grass (N and P).... second cutting	0.62	0.30	1A....	1.00	0.19
				2A....	1.01	0.40
				3A....	1.05	0.37
25.....	Malojillo grass (N and P).... second cutting	0.44	0.34	1D....	0.87	0.27
				3D....	0.95	0.51
9.....	Guatemala grass (N only).... first cutting	0.80	0.54	1B....	1.12	0.22
				2B....	1.18	0.19
				3B....	1.15	0.16
23.....	Guatemala grass (N only).... second cutting	0.69	0.55	1E....	1.00	0.19
				2E....	1.05	0.38
				3E....	1.15	0.22
10.....	Guatemala grass (N and P).. first cutting	0.83	0.43	1A....	1.34	0.19
				2A....	1.15	0.17
				3A....	1.24	0.16

TABLE 1—Continued

PER CENT NITROGEN IN FEED FED, REFUSE LEFT, FECES & URINE

(FEED, REFUSE AND FECES ANALYSES, PER CENT ON DRY BASIS.)

(URINE ANALYSES, PER CENT BY VOLUME.)

Trial No.	Ration	Nitrogen in Feed Fed %	Nitrogen in Refuse Left %	Animal	Nitrogen in Feces %	Nitrogen in Urine %
22.....	Guatemala grass (N and P).. second cutting	0.74	0.58	1D....	1.14	0.22
				3D....	1.12	0.21
24.....	Yaragua grass (N only)..... second cutting	0.42	0.37	1A....	1.29	0.33
				2A....	0.95	0.23
				3A....	0.97	0.29
17.....	Yaragua grass (N and P).... second cutting	0.54	0.32	1A....	0.98	0.12
				2A....	0.86	0.21
				3A....	0.95	0.21
26.....	Yaragua grass (N and P).... second cutting	0.49	0.33	1E....	0.98	0.22
				2E....	1.10	0.34
				3E....	1.16	0.24
15A....	Low protein diet.....	0.12	.....	1A....	0.62	0.10
				2A....	0.90	0.33
				3A....	0.94	0.84
30.....	Low protein diet..... Formula I	0.08	.....	1A....	0.92	0.11
				2A....	0.82	0.19
				3A....	0.80	0.12

TABLE 2

MAINTENANCE REQUIREMENT OF LAMBS AVERAGING 17.84 KILOGRAMS IN WEIGHT, BODY NITROGEN IN FECES PER GRAM OF DRY MATTER INGESTED AND BODY NITROGEN IN URINE PER 100 GRAMS OF BODY WEIGHT, BASED ON TEN-DAY TRIALS DURING WHICH NEARLY NITROGEN-FREE RATIONS WERE FED.

Trial No.	Animal No.	Average Weight Kg.	Dry Matter Ingested Gm.	Nitrogen in Feed Consumed %	Total Fecal Nitrogen Gm.	Total Urinary Nitrogen Gm.	Total Urinary & Fecal Nitrogen %	Fecal Nitrogen Per Gm. of Dry Matter Ingested	Urinary Nitrogen Per 100 Gm. Body Weight
1....	1-A...	18.35	4,245	0.17	13.80	12.71	26.51	0.0033	0.694
	2-A...	22.30	4,225	0.17	18.15	12.40	30.55	0.0043	0.556
	3-A...	18.00	3,660	0.17	15.48	8.92	24.40	0.0042	0.495
15....	1-A...	17.25	3,640	0.12	11.30	7.37	18.67	0.0048	0.427
	2-A...	15.85	2,830	0.12	16.71	6.35	23.06	0.0059	0.400
	3-A...	15.25	1,686	0.12	6.70	9.15	15.85	0.0040	0.600
30....	1-A...	20.48	2,920	0.08	11.98	9.90	21.88	0.0041	0.483
	2-A...	22.70	3,180	0.08	16.08	3.62	19.70	0.0051	0.159
	3-A...	20.83	2,800	0.08	10.15	4.75	14.90	0.0036	0.228
3....	1-B...	11.77	2,427	0.23	9.25	9.76	19.01	0.0038	0.830
	2-B...	16.55	3,089	0.23	14.22	10.38	24.60	0.0046	0.626
	3-B...	14.78	3,401	0.23	15.65	8.35	24.00	0.0046	0.565

TABLE 3

VALUES FOR BODY NITROGEN IN FECES PER GRAM OF DRY MATTER INGESTED AND BODY NITROGEN IN URINE PER KILOGRAM OF BODY WEIGHT AS OBTAINED BY DIFFERENT INVESTIGATORS WHEN NEARLY NITROGEN-FREE RATIONS ARE FED TO LAMBS

Remarks	Lamb No.	Body Nitrogen in Feces Per Gram of Dry Matter Ingested	Average Body Nitrogen in Feces Per Gram of Dry Matter Ingested	Body Nitrogen in Urine Per Kilogram of Body Weight	Average Body Nitrogen in Urine Per Kilogram of Body Weight
Sotola (2) performed two trials on each one of six lambs. Values given are average of the two trials (Black face lambs)	1	0.0075	.....	0.428	.....
	2	0.0068	.....	0.236	.....
	3	0.0059	.....	0.306	.....
	4	0.0064	.....	0.330	.....
	5	0.0070	.....	0.350	.....
	6	0.0058	0.0066	0.337	0.331
Turk Morrison & Maynard (6). These investigators used five animals and performed two trials on each animal. Values given are average of the two trials. (Young growing wether lambs)	1	0.0061	.....	0.556	.....
	2	0.0044	.....	0.480	.....
	3	0.0062	.....	0.360	.....
	4	0.0065	.....	0.552	.....
	5	0.0046	0.0056	0.393	0.468
Miller, Morrison and Maynard (7) report the following values obtained in 14 comparable experiments at the Cornell Station (Pure-bred and high-grade wether lambs of excellent mutton type used)	.....	0.0055	0.0055	0.370	0.370
The results obtained at the School of Tropical Medicine using six animals are given. Three trials were run on three of these animals and only one trial on the other three. The three trials in group A were run with a lapse of about five months between each trial; the average value obtained for the three trials is given. For animals of group B, the values obtained from the only trial run is given	1A	0.0041	.....	0.801	.....
	2A	0.0051	.....	0.335	.....
	3A	0.0035	.....	0.441	.....
	1B	0.0038	.....	0.830	.....
	2B	0.0046	.....	0.626	.....
	3B	0.0046	0.0043	0.565	0.526
(Wild Puerto Rican lambs ranging from six to eighteen months of age)					

TABLE 4

SUMMARY OF METABOLISM EXPERIMENTS UPON WHICH THE DETERMINATIONS OF BIOLOGICAL VALUES OF PROTEINS IN THE GRASSES IS BASED

Trial Number and Ration	Animal No.	Body Weight			Feed Intake Wet	Feed Intake Dry	N Intake	Total Fecal N	Body N in Feces	Food N in Feces	Absorbed N	Total N in Urine	Body N in Urine	Food N in Urine	Food N Retained	Biological Value	Ave. Biological Value
		Initial Kg.	Final Kg.	Ave. Kg.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.		
Trial 1																	
Low Protein	1-A...	19.10	17.70	18.35	4,280	4,245	7.22	13.80	13.80	.....	.....	12.71	12.71	.....	.....	.....	.....
Diet	2-A...	23.20	22.00	22.30	4,260	4,225	7.16	18.15	18.15	.....	.....	12.40	12.40	.....	.....	.....	.....
	3-A...	18.50	17.50	18.00	3,690	3,660	6.23	15.48	15.48	.....	.....	8.92	8.92	.....	.....	.....	.....
Trial 2																	
Corn Fodder	1-A...	17.80	21.20	19.50	25,385	5,915	98.30	35.00	25.41	9.59	88.71	22.10	10.25	11.85	76.86	87	.....
(N and P)	2-A...	21.60	23.40	22.50	24,791	5,811	97.20	32.80	25.00	7.80	89.40	22.55	11.82	10.73	78.67	88	86
	3-A...	16.55	18.40	17.48	20,305	4,659	81.60	27.00	20.02	6.98	74.62	22.41	9.20	13.11	61.51	83	.....
Trial 3	1-B...	12.08	11.45	11.77	2,561	2,427	5.61	9.25	9.25	.....	.....	9.76	9.76	.....	.....	.....	.....
Low Protein	2-B...	16.90	16.20	16.55	3,259	3,089	7.16	14.22	14.22	.....	.....	10.38	10.38	.....	.....	.....	.....
Diet	3-B...	15.05	14.50	14.78	3,588	3,401	7.85	15.65	15.65	.....	.....	8.35	8.35	.....	.....	.....	.....
Trial 4																	
Elephant Grass	1-A...	20.85	22.10	21.48	22,230	5,620	71.60	27.20	25.02	2.18	69.42	24.95	11.30	13.65	55.77	80	.....
(N only)	2-A...	23.40	24.20	23.80	20,557	5,367	67.60	24.50	23.10	1.40	66.20	26.90	12.74	14.16	52.04	79	80
	3-A...	17.90	19.50	18.70	19,552	5,052	67.20	24.78	21.80	2.98	64.22	22.20	9.85	12.35	51.87	81	.....
Trial 13																	
Elephant grass	1-B...	14.00	12.50	13.30	28,224	7,050	75.00	28.00	30.30	.....	75.00	21.60	7.00	14.60	60.40	81	81
(N only)																	
Trial 6																	
Elephant grass	1-A...	21.58	22.39	21.99	20,781	5,590	60.80	30.90	24.00	6.90	53.90	29.00	11.55	17.45	36.45	68	.....
(N and P)	2-A...	23.23	23.70	23.47	19,391	5,150	59.20	31.20	22.18	9.02	50.18	29.10	12.35	16.75	33.43	67	69
	3-A...	20.25	19.30	19.78	21,392	5,810	61.60	31.95	25.00	6.95	54.65	25.12	10.40	14.72	39.93	73	.....
Trial 11																	
Elephant grass	1-B...	14.30	14.30	14.30	31,660	6,432	88.80	28.60	27.61	0.99	87.81	21.80	7.55	14.25	73.56	84	.....
(N and P)	2-B...	20.40	20.70	20.55	35,107	6,850	89.10	39.70	29.40	10.30	78.80	27.24	10.80	16.44	62.36	79	80
	3-B...	16.10	16.55	16.33	33,878	6,648	87.95	31.50	28.60	3.90	84.05	27.60	8.60	19.00	65.05	77	.....
Trial 5																	
Guinea grass	1-B...	12.49	13.90	13.20	19,635	5,990	71.10	29.60	25.79	3.81	67.29	16.55	6.95	9.60	57.69	86	.....
(N only)	2-B...	18.10	20.20	19.15	21,785	6,590	74.50	28.90	28.30	0.60	73.90	27.50	10.09	17.41	56.49	77	80
	3-B...	16.55	15.33	15.99	20,108	6,110	71.70	27.95	26.21	1.74	69.96	24.80	8.43	16.37	53.59	77	.....
Trial 12																	
Guinea grass	1-A...	23.80	24.20	24.00	27,903	8,050	89.50	34.80	34.60	0.20	89.30	28.39	12.60	15.79	73.51	82	.....
(N only)	2-A...	23.40	28.10	25.25	26,960	8,170	90.00	43.90	35.10	8.80	81.20	21.50	13.30	8.20	73.00	90	86
	3-A...	19.40	21.5	20.45	26,078	7,820	74.70	31.00	33.60	3.40	71.30	21.50	10.74	10.76	60.54	85	.....
Trial 7																	
Guinea grass	1-B...	13.40	14.21	13.81	21,680	6,570	75.00	31.00	28.21	2.79	72.21	23.80	7.27	16.53	55.68	77	.....
(N and P)	2-B...	18.95	20.00	19.48	22,293	6,750	76.40	28.22	29.00	.....	76.40	29.60	10.23	16.67	59.73	78	77
	3-B...	16.35	15.90	16.13	19,554	5,960	65.50	28.00	25.60	3.40	63.10	23.75	8.50	15.25	47.85	76	.....
Trial 14																	
Guinea grass	1-A...	23.50	23.70	23.60	27,264	8,180	83.30	37.40	35.35	2.05	81.25	21.35	12.80	8.85	72.40	89	.....
(N and P)	2-A...	23.60	23.30	23.45	27,986	8,390	84.28	40.60	36.05	4.55	79.73	21.60	12.30	9.30	70.43	88	.....
	3-A...	20.00	20.09	20.05	24,761	7,430	79.90	36.00	32.00	4.00	75.90	17.55	10.57	6.98	68.92	86	89
Trial 8	1-A...	21.60	22.40														

Trial 14																		
Guinea grass (N and P)	1-A	23.50	23.70	23.60	27,264	8,180	83.30	37.40	35.35	2.05	81.25	21.35	12.80	8.85	72.40	89		
	2-A	23.60	23.30	23.45	27,986	8,390	84.28	40.60	36.05	4.55	79.73	21.60	12.30	9.30	70.43	88	89	
	3-A	20.00	20.09	20.05	24,761	7,430	79.90	36.00	32.00	4.00	75.90	17.55	10.57	6.98	68.92	91		
Trial 8																		
Malojillo grass (N only)	1-A	21.60	23.18	22.39	26,102	6,260	90.20	32.80	26.90	5.90	84.30	25.35	11.75	13.60	70.70	84		
	2-A	23.95	23.80	23.88	25,183	5,990	88.80	30.00	25.75	4.25	84.55	21.00	12.50	8.50	76.05	90	88	
	3-A	18.85	21.20	20.03	26,480	6,380	90.80	28.22	27.41	0.81	89.99	18.75	10.56	8.19	81.80	91		
Trial 27																		
Malojillo grass (N only)	1-A	20.80	21.20	21.00	19,104	8,550	51.20	30.90	36.80		51.20	9.66	11.07					
	2-A	20.50	20.80	20.65	21,034	9,160	53.55	30.20	39.40		53.55	12.40	10.88	1.52	52.03	97	97	
	3-A	19.10	19.40	19.25	19,968	8,820	52.20	28.95	38.20		52.20	8.76	10.10					
Trial 20																		
Malojillo grass (N and P)	1-A	21.20	23.40	22.30	26,231	7,240	59.75	36.16	31.10	5.06	54.69	18.40	11.72	6.68	48.01	88		
	2-A	20.70	21.70	21.20	26,216	7,240	59.75	38.02	31.10	6.92	52.83	19.30	11.17	8.13	44.70	85	89	
	3-A	18.50	20.40	19.45	23,696	6,430	57.30	33.18	27.61	5.57	51.73	12.78	10.22	2.56	49.17	95		
Trial 25																		
Malojillo grass (N and P)	1-D	20.20	21.20	20.70	19,923	6,500	34.30	28.75	28.00	0.75	33.55	14.40	10.90	3.50	30.05	91		
	3-D	13.01	14.85	13.93	15,757	4,780	28.50	23.50	20.59	2.91	25.59	9.57	7.35	2.22	23.37	91	91	
Trial 9																		
Guatemala grass (N only)	1-B	14.28	17.00	15.64	26,971	7,120	67.00	26.20	30.60		67.00	21.50	8.25	13.25	53.75	80		
	2-B	20.50	21.50	21.00	29,073	7,740	70.40	29.99	33.25		70.40	21.80	11.08	10.72	59.68	85	84	
	3-B	17.00	16.30	16.65	28,026	7,450	68.00	26.55	32.00		68.00	17.70	8.76	8.94	59.06	87		
Trial 23																		
Guatemala grass (N only)	1-E	14.43	16.05	15.24	19,370	6,720	48.80	23.22	28.85		48.80	17.90	8.02	9.88	38.92	80		
	2-E	12.68	14.85	13.77	14,273	4,130	40.00	16.95	17.75		40.00	14.90	7.25	7.65	32.35	81	81	
	3-E	12.42	14.84	13.63	13,814	4,000	39.50	18.71	17.20		39.50	14.70	7.19	7.51	31.99	81		
Trial 10																		
Guatemala grass (N and P)	1-A	22.80	22.70	22.75	26,969	6,380	67.42	31.80	27.41	4.39	63.03	23.15	11.96	11.19	51.84	82		
	2-A	24.80	23.60	24.20	28,285	6,755	69.00	28.50	29.00		69.00	22.50	11.83	10.67	58.33	85	85	
	3-A	18.95	20.60	19.78	28,690	6,860	69.50	31.40	29.50	1.90	67.60	19.10	10.40	8.70	58.90	87		
Trial 22																		
Guatemala grass (N and P)	1-D	18.70	21.20	19.95	23,023	7,100	61.20	25.40	30.50		61.20	21.92	10.50	11.42	49.78	81		
	3-D	12.81	12.88	12.88	15,019	4,730	47.50	20.00	20.03		47.50	11.61	6.77	4.84	42.66	90	86	
Trial 24																		
Yaragua grass (N only)	1-A	21.00	18.27	19.64	16,325	4,660	24.40	29.00	20.00	9.00	15.40	14.30	10.33	3.97	11.43	75		
	2-A	21.02	20.55	20.79	19,754	6,100	29.97	28.00	26.20	1.80	28.17	12.00	10.90	1.10	27.07	96	88	
	3-A	18.87	19.80	19.34	19,323	5,900	29.10	31.50	25.40	6.10	23.00	12.00	10.19	1.81	21.19	92		
Trial 17																		
Yaragua grass (N and P)	1-A	20.85	21.95	20.98	16,932	4,930	35.10	27.50	21.20	6.30	28.80	12.70	11.00	1.70	27.10	94		
	2-A	18.60	22.25	20.43	18,636	5,655	35.61	27.15	24.35	2.80	33.81	14.40	10.79	3.61	30.20	89	90	
	3-A	18.50	18.50	18.50	16,106	4,580	33.30	26.50	19.70	6.80	26.50	13.35	9.75	3.60	22.90	87		
Trial 26																		
Yaragua grass (N and P)	1-E	15.25	14.70	14.98	15,776	4,670	34.20	25.58	20.10	5.48	28.72	15.30	7.98	7.32	21.40	75	85	
	2-E	14.44	14.70	14.75	11,657	3,110	18.20	20.50	13.35	7.15	21.05	9.50	7.77	1.73	19.32	92	85	
	3-E	14.03	14.30	14.17	13,790	4,000	31.10	27.10	17.20	9.90	21.20	10.10	7.45	2.65	18.55	88		
Trial 15-A																		
Low Protein Diet	1-A	17.90	16.60	17.25	4,000	3,640	4.37	11.29	11.29			7.37	7.37					
	2-A	16.60	15.10	15.85	3,106	2,830	3.40	16.72	16.72			6.35	6.35					
	3-A	15.40	15.10	15.25	1,855	1,686	2.02	6.76	6.76			9.15	9.15					
Trial 30																		
Low Protein Diet	1-A	21.30	19.65	20.48	3,183	2,920	2.34	11.91	11.91			9.90	9.90					
	2-A	24.20	21.20	22.70	3,463	3,180	2.55	16.10	16.10			3.62	3.62					
	3-A	21.40	20.25	20.83	3,072	2,800	2.24	10.20	10.20			4.75	4.75					

TABLE 5

PROXIMATE ANALYSES, REPORTED ON DRY BASIS, OF THE FED AND REFUSED PORTIONS OF THE RATIONS USED IN THE DIFFERENT METABOLISM EXPERIMENTS

Ration	Crude Protein (N x 6.25) %		Fat %		Crude Fiber %		Nitrogen-free Extract %		Ash %	
	Feed fed	Feed refused	Feed fed	Feed refused	Feed fed	Feed refused	Feed fed	Feed refused	Feed fed	Feed refused
TRIAL No. 2: Corn fodder (fert. N and P) first cutting	9.50	8.12	4.31	2.87	30.90	27.20	49.30	55.83	5.99	5.98
TRIAL No. 4: Elephant grass (fert. N only) first cutting	5.06	2.12	3.60	2.28	36.35	41.45	47.63	49.45	7.36	4.70
TRIAL No. 13: Elephant grass (fert. N only) first cutting	5.44	2.50	2.61	2.12	37.25	39.60	44.10	46.92	10.60	8.86
TRIAL No. 6: Elephant grass (fert. N and P) first cutting	4.50	2.31	2.96	1.96	35.80	43.70	49.84	47.78	6.90	4.25
TRIAL No. 11: Elephant grass (fert. N and P) first cutting	7.50	3.26	3.24	2.53	32.88	37.00	45.98	48.16	10.40	9.05
TRIAL No. 5: Guinea grass (fert. N only) first cutting	5.87	3.88	2.76	1.69	38.20	39.40	43.52	46.15	9.65	8.88
TRIAL No. 12: Guinea grass (fert. N only) first cutting	5.44	2.50	2.14	1.48	34.05	39.75	46.57	46.92	11.80	9.35
TRIAL No. 7: Guinea grass (fert. N and P) first cutting	6.00	4.56	2.43	1.74	35.43	38.25	46.56	46.51	9.58	8.94
TRIAL No. 14: Guinea grass (fert. N and P) first cutting	5.18	2.78	2.60	1.86	33.80	35.93	46.27	46.25	12.15	13.18
TRIAL No. 8: Malojillo grass (fert. N only) first cutting	6.64	3.25	2.52	1.42	31.00	36.05	50.77	51.92	9.07	7.36
TRIAL No. 27: Malojillo grass (fert. N only) second cutting	3.11	2.39	1.79	1.32	33.05	32.90	56.35	58.85	5.70	4.54
TRIAL No. 20: Malojillo grass (fert. N and P) second cutting	3.88	1.88	1.97	1.43	32.50	34.88	53.39	55.62	8.26	6.19

TRIAL No. 25: Malojillo grass (fert. N and P) second cutting	2.75	2.12	1.74	1.61	32.50	35.95	55.79	54.06	7.22	6.26
TRIAL No. 9: Guatemala grass (fert. N only) first cutting	5.00	3.38	2.98	1.72	37.03	42.21	47.54	45.82	7.45	6.87
TRIAL No. 23: Guatemala grass (fert. N only) second cutting	4.31	3.44	2.47	1.75	33.40	34.96	51.79	52.72	8.03	7.13
TRIAL No. 10: Guatemala grass (fert. N and P) first cutting	5.19	2.69	2.89	1.97	35.55	38.15	47.71	48.67	8.66	8.52
TRIAL No. 22: Guatemala grass (fert. N and P) second cutting	4.62	3.65	2.68	2.32	31.25	35.25	53.20	50.90	8.25	7.88
TRIAL No. 24: Yaragua grass (fert. N only) second cutting	2.61	2.30	2.23	2.14	38.60	40.20	49.12	48.41	7.44	6.95
TRIAL No. 17: Yaragua grass (fert. N and P) second cutting	3.40	1.97	2.40	1.33	42.15	48.10	44.60	43.26	7.45	5.34
TRIAL No. 26: Yaragua grass (fert. N and P) second cutting	3.06	2.06	2.63	1.92	39.90	42.90	48.21	47.42	6.20	5.70

TABLE 6

PROXIMATE ANALYSES OF THE FECES, REPORTED ON DRY BASIS, AVERAGE COMPOSITE SAMPLE OF TEN-DAY METABOLISM EXPERIMENTS

Trial No.	Animal No.	Ration	Crude Protein (N x 6.25) %	Fat %	Crude Fiber %	Nitrogen-free Extract %	Ash %
1.....	1-A...	Low protein diet form I.....	4.30	.....	.....	.....	.....
	2-A...	Low protein diet form I.....	6.18	.....	.....	.....	.....
	3-A...	Low protein diet form I.....	5.68	.....	.....	.....	.....
2.....	1-A...	Corn fodder (fert. N and P) firts cutting.....	9.44	2.53	23.55	52.78	11.70
	2-A...	Corn fodder (fert. N and P) first cutting.....	9.19	2.31	24.34	53.35	10.81
	3-A...	Corn fodder (fert. N and P) first cutting.....	8.60	2.69	24.45	51.68	12.58
3.....	1-B...	Low protein diet form I.....	5.25	.....	.....	.....	.....
	2-B...	Low protein diet form I.....	5.75	.....	.....	.....	.....
	3-B...	Low protein diet form I.....	6.55	.....	.....	.....	.....
4.....	1-A...	Elephant grass (fert. N only) first cutting.....	6.67	3.06	24.80	50.02	15.45
	2-A...	Elephant grass (fert. N only) first cutting.....	6.67	3.04	27.55	46.93	15.81
	3-A...	Elephant grass (fert. N only) first cutting.....	6.44	3.06	30.00	46.30	14.20
13.....	1-B...	Elephant grass (fert. N only) first cutting.....	6.30	2.79	29.90	45.11	15.90
6.....	1-A...	Elephant grass (fert. N and P) first cutting.....	6.81	3.23	31.37	42.86	15.73
	2-A...	Elephant grass (fert. N and P) first cutting.....	7.30	3.37	26.35	47.40	15.58
	3-A...	Elephant grass (fert. N and P) first cutting.....	6.68	3.18	29.90	46.17	14.07
11.....	1-B...	Elephant grass (first N and P) first cutting.....	7.14	2.62	29.10	45.34	15.80
	2-B...	Elephant grass (fert. N and P) first cutting.....	7.45	3.04	30.50	43.20	15.81
	3-B...	Elephant grass (fert. N and P) first cutting.....	6.75	2.76	31.51	43.28	15.70
5.....	1-B...	Guinea grass (fert. N only) first cutting.....	5.94	2.48	32.14	43.63	15.81
	2-B...	Guinea grass (fert. N only) first cutting.....	5.75	2.39	32.28	43.78	15.80
	3-B...	Guinea grass (fert. N only) first cutting.....	5.81	2.26	32.97	42.31	16.65
12.....	1-A...	Guinea grass (fert. N only) first cutting.....	6.06	3.04	31.05	40.15	19.70
	2-A...	Guinea grass (fert. N only) first cutting.....	6.75	2.89	29.04	39.92	21.40
	3-A...	Guinea grass (fert. N only) first cutting.....	6.75	2.74	26.09	43.42	21.00
7.....	1-B...	Guinea grass (fert. N and P) first cutting.....	6.19	2.94	32.86	42.10	15.91
	2-B...	Guinea grass (fert. N and P) first cutting.....	6.19	2.81	33.15	41.40	16.45
	3-B...	Guinea grass (fert. N and P) first cutting.....	6.00	2.93	30.40	43.47	17.20
14.....	1-A...	Guinea grass (fert. N and P) first cutting.....	6.30	2.56	28.47	41.29	21.38
	2-A...	Guinea grass (fert. N and P) first cutting.....	6.37	2.34	28.55	40.33	22.41
	3-A...	Guinea grass (fert. N and P) first cutting.....	6.19	2.36	27.20	42.45	21.80
8.....	1-A...	Malojillo grass (fert. N only) first cutting.....	8.00	3.57	28.35	44.48	15.60
	2-A...	Malojillo grass (fert. N only) first cutting.....	8.55	3.55	22.50	47.90	17.50
	3-A...	Malojillo grass (fert. N only) first cutting.....	7.56	3.10	26.70	48.24	14.40

TABLE 6—Continued

PROXIMATE ANALYSES OF THE FECES, REPORTED ON DRY BASIS, AVERAGE COMPOSITE SAMPLE OF TEN-DAY METABOLISM EXPERIMENTS

Trial No.	Animal No.	Ration	Crude Protein (N x 6.25) %	Fat %	Crude Fiber %	Nitrogen-free Extract %	Ash %
27	1-A	Malojillo grass (fert. N only) second cutting	6.38	1.69	33.50	48.13	10.30
	2-A	Malojillo grass (fert. N only) second cutting	5.56	1.89	31.85	50.08	10.62
	3-A	Malojillo grass (fert. N only) second cutting	5.06	1.72	33.85	48.47	10.90
20	1-A	Malojillo grass (fert. N and P) second cutting	6.25	1.92	30.66	* 46.57	14.60
	2-A	Malojillo grass (fert. N and P) second cutting	6.31	1.22	32.70	46.27	13.50
	3-A	Malojillo grass (fert. N and P) second cutting	6.56	1.36	30.10	47.13	14.85
25	1-D	Malojillo grass (fert. N and P) second cutting	5.45	1.90	35.35	43.80	13.50
	3-D	Malojillo grass (fert. N and P) second cutting	5.94	1.82	35.30	44.04	12.90
9	1-B	Guatemala grass (fert. N only) first cutting	7.00	2.46	31.35	47.24	11.95
	2-B	Guatemala grass (fert. N only) first cutting	7.37	2.28	32.08	45.58	12.70
	3-B	Guatemala grass (fert. N only) first cutting	7.19	2.31	30.23	47.87	12.40
23	1-E	Guatemala grass (fert. N only) second cutting	6.25	2.67	30.12	47.96	13.60
	2-E	Guatemala grass (fert. N only) second cutting	6.56	2.24	31.21	45.69	14.30
	3-E	Guatemala grass (fert. N only) second cutting	7.20	2.30	30.05	45.20	15.25
10	1-A	Guatemala grass (fert. N and P) first cutting	8.38	2.49	32.30	43.53	13.30
	2-A	Guatemala grass (fert. N and P) first cutting	7.19	2.34	30.95	45.92	13.60
	3-A	Guatemala grass (fert. N and P) first cutting	7.75	2.35	31.81	45.09	13.00
22	1-D	Guatemala grass (fert. N and P) second cutting	7.13	2.19	30.45	45.63	14.60
	3-D	Guatemala grass (fert. N and P) second cutting	7.00	2.32	29.35	46.13	15.20
24	1-A	Yeregua grass (fert. N only) second cutting	8.05	2.99	28.73	44.58	15.65
	2-A	Yeregua grass (fert. N only) second cutting	5.94	2.88	30.60	46.18	14.40
	3-A	Yeregua grass (fert. N only) second cutting	6.05	3.22	30.90	45.33	14.50
17	1A	Yeregua grass (fert. N and P). second cutting	6.13	2.56	29.20	45.81	16.30
	2-A	Yeregua grass (fert. N and P) second cutting	5.37	2.19	31.45	46.29	14.70
	3-A	Yeregua grass (fert. N and P) second cutting	5.94	2.98	29.09	45.89	16.10
26	1-E	Yeregua grass (fert. N and P) second cutting	6.13	3.93	30.50	44.64	14.80
	2-E	Yeregua grass (fert. N and P) second cutting	6.87	3.92	31.00	44.81	13.40
	3-E	Yeregua grass (fert. N and P) second cutting	7.25	4.10	29.25	45.19	14.21
15-A	1-A	Low protein diet form I	3.88	.....	.....	.....	.....
	2-A	Low protein diet form I	5.62	.....	.....	.....	.....
	3-A	Low protein diet form I	5.87	.....	.....	.....	.....
30	1-A	Low protein diet form II	5.75	.....	.....	.....	.....
	2-A	Low protein diet form II	5.11	.....	.....	.....	.....
	3-A	Low protein diet form II	4.97	.....	.....	.....	.....

TABLE 7

COEFFICIENTS OF APPARENT DIGESTIBILITY

Trial No.	Ration	Animal No.	Dry Matter %	Crude Protein (N x 6.25)%	Fat %	Crude Fiber %	Nitrogen-free Extract %	Ash %	Organic Matter %
2.e	Corn fodder (N and P) first cutting in flower	1-A	62	66	82	73	56	27	66
		2-A	63	67	84	73	56	33	65
		3-A	59	68	81	71	50	14	62
	AVERAGE		61	67	82	72	54	24	64
4	Elephant grass (N only) first cutting before flowering	1-A	57	63	72	66	53	31	66
		2-A	58	65	74	63	57	33	61
		3-A	53	64	72	54	53	36	54
	AVERAGE		56	64	73	61	54	33	60
13	Elephant grass (N only) first cutting before flowering	1-B	61	63	61	68	59	45	63
	AVERAGE		61	63	61	68	59	45	63
6	Elephant grass (N and P) first cutting before flowering	1-A	49	49	59	43	58	17	53
		2-A	48	47	58	48	53	20	51
		3-A	49	48	58	46	54	24	51
	AVERAGE		49	48	58	46	54	20	52
11	Elephant grass (N and P) first cutting before flowering	1-B	61	67	70	65	61	42	64
		2-B	51	56	56	54	54	27	54
		3-B	55	63	63	56	57	33	57
	AVERAGE		56	62	63	58	57	34	58
5	Guinea grass (N only) first cutting in flower	1-B	48	58	64	56	46	19	59
		2-B	52	62	67	59	51	26	55
		3-B	50	60	68	57	50	19	55
	AVERAGE		50	60	66	57	49	21	56
12	Guinea grass (N only) first cutting in flower	1-A	53	59	42	53	60	29	58
		2-A	50	51	41	54	58	18	51
		3-A	56	58	52	63	59	30	60
	AVERAGE		53	56	45	57	59	28	56
7	Guinea grass (N and P) first cutting in flower	1-B	52	59	53	53	57	25	55

7.....	Guinea grass (N and P) first cutting in flower.....	1-B.....	52	59	53	53	57	25	55
		2-B.....	58	64	60	58	63	31	60
		3-B.....	51	60	54	55	54	17	55
	AVERAGE.....	.....	53	61	56	55	58	24	63
14.....	Guinea grass (N and P) first cutting in flower.....	1-A.....	55	55	60	61	60	17	60
		2-A.....	53	52	62	59	59	9	58
		3-A.....	51	55	63	59	55	7	57
	AVERAGE.....	.....	53	54	62	60	58	11	58
8.....	Malojillo grass (N and P) first cutting before flowering.	1-A.....	59	64	56	58	64	38	67
		2-A.....	64	66	62	70	65	38	73
		3-A.....	63	69	65	65	65	49	70
	AVERAGE.....	.....	62	66	61	64	64	42	71
27.....	Malojillo grass (N only) second cutting in flower.....	1-A.....	65	39	73	65	69	46	66
		2-A.....	63	43	62	65	66	39	65
		3-A.....	61	46	68	60	65	35	63
	AVERAGE.....	.....	63	42	68	63	67	40	65
20.....	Malojillo grass (N and P) second cutting in flower....	1-A.....	50	39	59	51	55	24	53
		2-A.....	48	36	73	45	54	31	50
		3-A.....	51	42	73	52	55	27	54
	AVERAGE.....	.....	50	39	68	49	55	27	52
25.....	Malojillo grass (N and P) second cutting in flower	1-D.....	49	16	57	40	61	16	52
		3-D.....	48	17	51	.....	60	22	50
	AVERAGE.....	.....	32	17	54	40	61	19	51
9.....	Guatemala grass (N only) first cutting before flowering..	1-B.....	67	61	78	70	68	50	69
		2-B.....	67	58	79	70	69	46	69
		3-B.....	69	61	81	73	70	50	71
	AVERAGE.....	.....	68	60	79	71	69	49	70
23.....	Guatemala grass (N only) second cutting before flowering	1-E.....	59	52	75	62	62	39	58
		2-E.....	61	58	78	60	64	43	63
		3-E.....	59	53	77	59	63	38	61
	AVERAGE.....	.....	60	54	77	60	63	40	61

TABLE 7—Continued

COEFFICIENTS OF APPARENT DIGESTIBILITY

Trial No.	Ration	Animal No.	Dry Matter %	Crude Protein (N x 6.25)%	Fat %	Crude Fiber %	Nitrogen-free Extract %	Ash %	Organic Matter %
10	Guatemala grass (N & P) first cutting before flowering.	1-A	63	53	73	65	66	44	65
		2-A	63	59	74	67	64	43	65
		3-A	63	55	74	67	65	45	65
	AVERAGE		63	56	74	66	65	44	65
22	Guatemala grass (N & P) second cutting before flowering.	1-D	69	58	77	66	74	47	71
		3-D	62	57	73	54	70	35	65
	AVERAGE		66	58	75	60	72	41	68
24	Yaragua grass (N only) second cutting before flowering.	1-A	52		41	61	57	11	56
		2-A	52	5	41	60	56	14	55
		3-A	45		25	54	51	2	49
	AVERAGE		50	5	36	58	50	9	53
17	Yaragua grass (N & P) second cutting before flowering.	1-A	43	23	55	56	43		48
		2-A	44	27	58	55	43	3	48
		3-A	39	21	45	52	39		44
	AVERAGE		42	24	53	54	42	3	47
26	Yaragua grass (N & P) second cutting before flowering.	1-E	44	25	41	45	50		59
		2-E	40	29	49	40	46		44
		3-E	42	13	38	51	47		46
	AVERAGE		42	22	43	45	48		50

TABLE 8

DIGESTIBLE NUTRIENTS IN 100 LBS. OF PUERTO RICAN FEEDING STUFFS AS CUT

Feeding stuff	Total dry matter	Digestible Nutrients				Nutritive ratio
		Crude Protein	Fat	Carbo-hydrates	Total (inc. fat x 2.25)	
1 Corn fodder (fert. N and P) first cutting	23.79	1.51	0.84	11.71	13.60	1:9.0
4 Elephant grass (fert. N only) first cutting	27.68	0.90	0.73	13.06	14.75	1:16.4
18 Elephant grass (fert. N only) first cutting	24.60	0.85	0.39	12.64	13.52	1:16.0
6 Elephant grass (fert. N and P) first cutting	30.08	0.63	0.52	13.05	14.22	1:22.5
11 Elephant grass (fert. N and P) first cutting	19.23	0.90	0.39	8.70	9.58	1:10.6
5 Guinea grass (fert. N only) first cutting	29.44	1.05	0.54	12.20	13.42	1:12.8
12 Guinea grass (fert. N only) first cutting	29.84	0.91	0.29	14.00	14.66	1:16.1
7 Guinea grass (fert. N and P) first cutting	29.64	1.08	0.40	13.81	14.71	1:13.6
14 Guinea grass (fert. N and P) first cutting	30.00	0.84	0.48	14.05	15.13	1:18.0
8 Malojillo grass (fert. N only) first cutting	26.18	1.15	0.40	13.70	14.60	1:12.7
27 Malojillo grass (fert. N only) second cutting	37.90	0.50	0.46	22.33	23.37	1:46.7
20 Malojillo grass (fert. N and P) second cutting	29.10	0.44	0.39	12.27	13.15	1:30.0
26 Malojillo grass (fert. N and P) second cutting	34.00	0.21	0.32	17.57	18.29	1:87.0
9 Guatemala grass (fert. N only) first cutting	27.00	0.81	0.64	15.20	16.64	1:20.6
28 Guatemala grass (fert. N only) second cutting	30.50	0.70	0.57	16.40	17.68	1:25.2
10 Guatemala grass (fert. N and P) first cutting	24.60	0.72	0.53	13.42	14.62	1:20.4
22 Guatemala grass (fert. N and P) second cutting	30.40	0.81	0.62	17.30	18.70	1:23.1
24 Yaragua grass (fert. N only) second cutting	36.30	0.05	0.29	17.08	17.74	1:35.4
17 Yaragua grass (fert. N and P) second cutting	34.00	0.28	0.44	14.13	15.12	1:54.0
26 Yaragua grass (fert. N and P) second cutting	34.80	0.23	0.40	14.30	15.20	1:66.2

Note: "N and P" stands for nitrogen and phosphorus in the fertilizer.
"N" stands for nitrogen only in the fertilizer.

TABLE 9

PROXIMATE ANALYSES OF THE GRASSES USED IN THE NUTRITIONAL EXPERIMENTS AS CUT (WET BASIS)

Trial No.	Dates on which the grasses were collected at Río Piedras	Name of the grass	Total moisture as fed %	Crude protein (N x 6.25)%	Fat %	Crude fiber %.	N-free extract %	Ash %	Calcium %	Phosphorus %
2.....	August 27 to September 5, 1936.....	Corn fodder (N and P) first cutting in flower	76.21	2.26	1.02	7.35	11.74	1.42	0.0621	0.0415
4.....	September 22 to October 2, 1936.....	Elephant grass (N only) first cutting before flowering	72.32	1.40	1.00	10.10	12.78	2.40	0.0582	0.0393
13.....	January 6 to January 16, 1937.....	Elephant grass (N only) first cutting before flowering	75.40	1.34	0.64	9.18	10.83	2.61	0.0825	0.0430
6.....	October 3 to October 23, 1936.....	Elephant grass (N and P) first cutting before flowering ..	69.92	1.31	0.89	10.79	15.01	2.08	0.0866	0.0425
11.....	December 16 to December 26, 1936....	Elephant grass (N and P) first cutting before flowering ...	80.77	1.44	0.62	6.34	8.83	2.00	0.0640	0.0420
5.....	October 3 to October 23, 1936.....	Guinea grass (N only) first cutting in flower	70.56	1.73	0.81	11.21	11.85	3.84	0.0983	0.0347
12.....	December 16 to December 26, 1936....	Guinea grass (N only) first cutting in flower	70.16	1.62	0.64	10.18	13.88	3.52	0.1330	0.0630
7.....	November 4 to November 14, 1936....	Guinea grass (N and P) first cutting in flower	70.36	1.78	0.72	10.50	13.80	2.84	0.1050	0.0456
14.....	January 6 to January 16, 1937.....	Guinea grass (N and P) first cutting in flower	70.16	1.56	0.78	10.15	13.70	3.65	0.1430	0.0741
8.....	November 4 to November 14, 1936....	Malojillo grass (N only) first cutting before flowering	73.82	1.74	0.66	8.11	13.30	2.37	0.0772	0.0374
27.....	April 28 to May 8, 1937.....	Malojillo grass (N only) second cutting in flower	62.10	1.18	0.68	12.50	15.53	2.41	0.0718	0.0383
20.....	March 15 to March 25, 1937.....	Malojillo grass (N and P) second cutting in flower	70.90	1.13	0.57	9.46	19.12	2.45	0.0854	0.0500
25.....	April 17 to April 27, 1937.....	Malojillo grass (N and P) second cutting in flower	66.00	0.94	0.59	10.90	12.83	2.01	0.0485	0.0335
9.....	November 25 to December 5, 1936.....	Guatemala grass (N only) first cutting before flowering..	73.00	1.35	0.81	10.00	16.03	2.42	0.0546	0.0450

23.....	March 26 to April 5, 1937.....	Guatemala grass (N only) second cutting before flowering	69.50	1.30	0.74	10.01	11.73	2.13	0.0448	0.0335
10.....	November 25 to December 5, 1936.....	Guatemala grass (N and P) first cutting before flowering ..	75.40	1.28	0.71	8.75	16.18	2.50	0.0523	0.0441
22.....	March 26 to April 5, 1937.....	Guatemala grass (N and P) second cutting before flowering	69.60	1.40	0.82	9.50	16.18	2.50	0.0523	0.0441
24.....	April 6 to April 16, 1937.....	Yaragua grass (N only) second cutting before flowering	63.70	0.95	0.81	14.00	17.84	2.70	0.1248	0.0581
17.....	February 20 to March 2, 1937.....	Yaragua grass (N and P) second cutting before flowering	66.00	1.16	0.82	14.30	15.20	2.52	0.0950	0.0443
26.....	April 17 to April 27, 1937	Yaragua grass (N and P) second cutting before flowering	65.20	1.06	0.92	13.90	16.76	2.16	0.0973	0.0613

TABLE 10

ANALYSES OF THE GRASSES ON DRY BASIS

Name of the Grass	Total Solids %	Crude Protein (N x 6.25) %	Fat %	Crude Fiber %	Nitrogen Free Extract %	Ash %	Ca %	P %	P. Ca %
Corn fodder (N and P) first cutting	23.79	9.50	4.31	30.90	49.30	5.99	0.262	0.180	1:1.45
Elephant grass (N only) first cutting	27.68	5.06	3.60	36.35	47.63	7.36	0.210	0.142	1:1.48
Elephant grass (N only) first cutting	24.60	5.44	2.61	37.25	44.10	10.60	0.335	0.175	1:1.90
Elephant grass (N and P) first cutting	30.08	4.50	2.96	35.80	49.84	6.90	0.288	0.138	1:2.08
Elephant grass (N and P) first cutting	19.23	7.50	3.24	32.88	45.98	10.40	0.323	0.218	1:1.48
Guinea grass (N only) first cutting	29.44	5.87	2.76	38.20	43.52	9.65	0.334	0.117	1 2.86
Guinea grass (N only) first cutting	29.84	5.44	2.14	34.05	46.57	11.80	0.445	0.214	1:2.08
Guinea grass (N and P) first cutting	29.64	6.00	2.43	35.43	46.56	9.58	0.346	0.154	1:2.24
Guinea grass (N and P) first cutting	30.00	5.18	2.60	33.80	46.27	12.15	0.477	0.247	1:1.93
Malojillo grass (N only) first cutting	26.18	6.64	2.52	31.00	50.77	9.07	0.295	0.143	1:2.06
Malojillo grass (N only) second cutting	37.90	3.11	1.79	33.05	56.35	5.70	0.212	0.108	1:2.05
Malojillo grass (N and P) second cutting	29.10	3.88	1.97	32.50	53.39	8.26	0.246	0.132	1:1.86
Malojillo grass (N and P) second cutting	34.00	2.75	1.74	32.50	55.79	7.22	0.251	0.147	1:1.70
Guatemala grass (N only) first cutting	27.00	5.00	2.98	37.03	47.54	7.45	0.180	0.124	1:1.45
Guatemala grass (N only) second cutting	30.50	4.31	2.47	33.40	51.79	8.03	0.182	0.147	1:1.24
Guatemala grass (N and P) first cutting	24.60	5.19	2.89	35.55	47.71	8.66	0.182	0.136	1:1.34
Guatemala grass (N and P) second cutting	30.40	4.62	2.68	31.25	53.20	8.25	0.188	0.145	1:1.30
Yaragua grass (N only) second cutting	36.30	2.61	2.23	38.60	49.12	7.44	0.343	0.160	1:2.14
Yaragua grass (N and P) second cutting	34.00	3.40	2.40	42.15	44.60	7.45	0.279	0.130	1:2.14
Yaragua grass (N and P) second cutting	34.80	3.06	2.63	39.90	48.21	6.20	0.279	0.176	1:1.59

N and P stand for nitrogen and phosphorus in the fertilizer.
N stand for nitrogen only in the fertilizer.

TABLE 11

SUMMARY OF THE NUTRITIVE INDEXES DETERMINED IN THE EXPERIMENTS PERFORMED DURING THE YEAR OF 1936-37

Ration	Dates on which Samples were collected	Coefficients of apparent digestibility							Biological Value of Protein	Nutritive Ratio 1 to	P: Ca Ratio 1 to
		Dry Matter	Crude Protein	Fat	Crude Fiber	N free Extract	Ash	Organic Matter			
TRIAL No. 2: Corn fodder fert. N and P first cutting	August 27 to Sept. 5, 1935	61	67	82	72	54	24	64	86	9	1.45
TRIAL No. 4: Elephant grass fert. N only first cutting	September 22 to October 2, 1936	56	64	73	61	54	33	60	80	16.4	1.48
TRIAL No. 13: Elephant grass fert. N only first cutting	January 6 to January 16, 1937	61	63	61	68	59	45	63	81	16.0	1.90
TRIAL No. 6: Elephant grass fert. N and P first cutting	October 13 to October 23, 1936	49	48	58	46	54	20	52	69	22.5	2.08
TRIAL No. 11: Elephant grass fert. N only first cutting	December 16 to Dec. 26, 1935	56	62	63	58	57	34	58	80	10.6	1.48
TRIAL No. 5: Guinea grass fert. N only first cutting	October 13 to October 23, 1935	50	60	66	57	49	21	56	80	12.8	2.86
TRIAL No. 12: Guinea grass fert. N only first cutting	December 16 to Dec. 26, 19236	53	56	45	57	59	28	56	86	16.1	2.08
TRIAL No. 7: Guinea grass fert. N and P first cutting	November 4 to Nov. 14, 1936	53	61	56	55	58	24	63	77	13.6	2.24
TRIAL No. 14: Guinea grass fert. N and P first cutting	January 6 to Jan. 16, 1937	53	54	62	60	58	11	58	89	18.0	1.93
TRIAL No. 8: Malojillo or Para grass fert. N only first cutting	November 4 to Nov. 14, 1936	62	66	61	64	64	42	71	88	12.7	2.06
TRIAL No. 27: Malojillo or Para grass fert. N only 2nd. cutting	April 28 to May 8, 1937	63	42	68	63	67	40	65	97	46.7	1.205
TRIAL No. 20: Malojillo or Para grass fert. N & P 2nd. cutting	March 15 to March 25, 1937	50	39	68	49	55	27	52	89	30.0	1.86
TRIAL No. 25: Malojillo or Para grass fert. N & P 2nd. cutting	April 17 to April 27, 1937	32	17	54	40	61	19	51	91	87.0	1.70

TRIAL No. 9: Guatemala grass fert. N only first cutting	November 25 to Dec. 5, 1936	68	60	79	71	69	49	70	84	20.6	1.48
TRIAL No. 23: Guatemala grass fert. N only second cutting	March 26 to April 5, 1937	60	54	77	60	65	40	61	81	25.2	1.24
TRIAL No. 23: Guatemala grass fert. N and P first cutting	November 25 to Dec. 5, 1936	63	56	74	66	65	44	65	85	20.4	1.34
TRIAL No. 10: Guatemala grass fert. N and P second cutting	March 26 to April 5, 1937	66	58	74	60	72	41	68	86	23.1	1.30
TRIAL No. 24: Yaragua grass fert. N only second cutting	April 6 to April 16, 1937.	50	5	35	58	50	9	53	88	354.0	2.14
TRIAL No. 17: Yaragua grass fert. N and P second cutting	February 20 to March 2, 1937	42	24	53	54	42	3	47	90	54.0	2.14
TRIAL No. 26: Yaragua grass fert. N and P second cutting	April 17 to April 27, 1937.	42	22	43	45	48	Neg. bal.	50	85	66.2	1.59

Note: "N and P" stands for nitrogen and phosphorus in the fertilizer.
"N" stands for nitrogen only in the fertilizer.

TABLE 12

VITAMIN A ACTIVITY OF CROPS

Crops	Vitamin A Units per gram (Sherman)
Para grass leaves	200
Guinea grass leaves	200
Guatemala grass leaves	270
Elephant grass leaves	200
Yaragua grass leaves	100
White pigeon peas, (flowers, stems, leaves, air-dry)	333
Velvet Beans (pods, leaves and stems, air-dry)	135

A COMPARISON OF METHODS OF DETERMINING CARBON IN SOILS

CARLOS ESTEVA JR.[1]

INTRODUCTION

For the determination of organic carbon in soils various methods have been proposed and they may be classified as followows:

1. Dry combustion:
   (*a*) Furnace combution.
   (*b*) Bomb combution or Parr's method. An oxidation with sodium peroxide in which sodium carbonate is formed.
2. Wet combustion: In which the material to be analyzed is treated with a mixture of chromic and sulfuric acids. Various modifications of this method have been proposed.

It has been shown experimentally that the dry combustion methods give higher results than the wet combution, but the former have certain disadvantages which may be summarized in the following way. The dry combustion methods require a rather complicated and expensive equipment and it is somewhat more difficult to manipulate. In some cases (especially in the furnace dry combustion) the determination is very long and tedious. The wet oxidation methods are adaptable for the estimation of carbon, both in solutions and in dry substances, while the dry combustion methods are only adaptable for the estimation of carbon in dry substances.

Naturally, the aim of many investigators had been to obtain a wet ovidation method, capable of determining the total carbon in amounts that would compare with the dry combustion methods.

White and Holben (**14**) claim that they have found the ideal method: a wet oxidation process which is capable of determining amounts of carbon identical with those obtained by the dry combustion methods.

This work was undertaken with the purpose of comparing the relative efficiency of the chromic acid method as given by White and Holben (**14**) and the official method as given by the Official and Tentative Methods of Analysis of the Association of Agricultural Chemists (**7**), with the Parr's dry combustion process.

[1] The writer wishes to express his obligation to Dr. J. A. Bizzell under whose direction and help this work was undertaken.

Review of Literature

In 1848 Rogers and Rogers (**9**) devised a wet oxidation method for the determination of carbon in native and artificial graphites. The oxidizing agent employed in this process was a mixture of bichromate of potassium and sulfuric acid, which the authors claimed, that when applied to graphite, under the conditions given, converted the carbon rapidly and completely into carbon dioxide. The process was gravimetric.

In 1880 Warington and Peake (**12**) furnished data which led to the conclusion that oxidation of carbon in soils by means of a mixture of chromic and sulfuric acids gave results lower than those obtained by the furnace combustion in a current of oxygen. The mode of procedure was quite similar to that recommended by E. Wolff in his "Anleitung zur Chemischen Untersuchung Landwirthschaftlich Wichtiger Stoffe". The materials were kept below their boiling point by heating in a water bath. They stated, however, that the complete destruction of the humic material in the soil does not necessarily imply that the carbon has been entirely converted to carbon dioxide. They used a gravimetric method. The oxidation with the permanganate method, as used by the authors indicated higher result than with chromic acid; but even the permanganate method failed to convert the whole of the carbon to carbon dioxide, the product with the permanganate being, on an average of 4 soils, 92.4 per cent of that yielded by the combustion in oxygen.

In 1904 Cameron and Breazeale (**4**) confirmed the ideas of Warington and Peake (**12**) by stating that the oxidation of carbon in soils by the mixture of chromic and sulfuric acids gave results lower than those obtained by the furnace combustion. But they concluded that the combustion of a soil by the wet method with chromic acid mixture, as described in their paper, would give a more accurate idea of the organic matter in the soil, than the furnace combustion method. Beside the method was more rapid.

n this same year Parr (**8**) published his new method of determining carbon. The combustion of the organic material is affected by means of sodium peroxide, the charge being contained in a closed bomb or cartridge surrounded by water. He claims that the method is much more accurate than the various forms of alkalimeters, which were tried for comparison, and that its ease of manipulation renders it preferable to the absorption method, especially for technical work.

Hall and Miller (**6**) in 1906 reexamined the chromic acid method and concluded that the error was due to incomplete oxidation, other

substances than carbon dioxide being produced. They found that by passing the products of combustion over heated copper oxide all the carbon would be obtained as carbon dioxide.

Ames and Geither (**1**) in 1914 concluded that if boiled for 30 minutes a mixture of 3.3 grams chromic acid in 10 cc. water to 50 cc. of sulfuric acid (sp. gr. 1.84) will oxidize all the organic carbon and liberate carbon dioxide chemically or mechanically held in soils, provided the soil is ground to pass thru a 60 mesh sieve. One to three grams of soil were used for each 60 cc. of mixture. They made no attempt to prevent the acid fumes passing into the carbon dioxide absorption tower. They used a wet combustion volumetric method.

Schollenberger (**10**) in 1916 suggested certain improvements in the method described by Ames and Gaither (**1**). The changes referred to, consist of the use of a mixture of phosphoric and sulfuric acids, instead of sulfuric acid alone, with chromic anhydride as the oxidizing agent. Also the substitution of barium hydroxide for sodium hydroxide as the alkaline absorbent for carbon dioxide. He also suggested the replacement of the modified Camp absorption by the Meyer absorption apparatus or Truog's bead tower, together with changes in procedure made necessary by the changes in the reagents employed. The partial substitution of phosphoric for sulfuric acid reduces to a negligible quantity the fuming noticed when sulfuric acid is used alone. Phosphoric acid alone gave invariably lower results.

Gortner (**5**) in 1916 kept the digestion mixture below the boiling point for 2.5 hours and passed the products of combustion thru a heated combustion tube.

Finally in 1925 White and Holben (**14**) published their new method entitled, "Perfection of Chromic Acid Method for Determining Organic Carbon". The authors claim that their method has the following advantages. (**1**) The sulfur-trioxide absorption tube, used for the first time in this study greatly simplifies the usual analytical procedure. (**2**) Eliminates the use of a combustion tube. (**3**) The proposed method has the advantage over the dry combustion method in that it eliminates the possibility of leaving behind the residue of undecomposed carbonates. (**4**) It may be used for the estimation of carbon both in solution and in dry substances. (**5**) The use of the proposed sulfur trioxide absorption tube eliminates the necessity of secondary combustion. (**7**) The results compare with the furnace comustion with CuO and with th bomb combustion.

Experimental

The plan of the investigation included the analysis of 25 soil samples, of high and low carbon content, representative of the type found in the State of New York. The analysis included determinations of organic carbon by the Official Wet Oxidation Method and the chromic acid method of White and Holben (**14**). The results were compared with those obtained by Waterman (**13**) following the Parr combustion procedure.

Soils Used: The samples were taken by the Department of Agronomy (Cornel University) some years ago, and accurate records were taken of the location so that at any future time duplicate samples might be taken at exactly the same place.

Preparation of Sample: In general, soil samples were taken at a depth of eight inches by the method described in the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists (**7**) .When received in the laboratory the samples were spread out and allowed to air-dry. The original air-dry samples were thoroughly mixed and a subsample taken for analysis. The subsamples were rubbed in a porcelain mortar, using a rubber tipped pestle, and then passed thru a sieve having circular perforation 1 mm. in diameter. The material not passing the sieve was discarded. The sifted subsamples were then ground in an agate mortar until they passed entirely thru a sieve having 100 meshes to the linear inch.

Organic Carbon: Was determined by analyzing for total carbon and then substracting the inorganic carbon obtained.

Description of Methods

I. The Official Wet Oxidation Method.

Detailed Procedure: With slight changes the procedure listed in page 25 of the Official Methods (**7**) was followed.

Having the apparatus set as in Figures 1 and the solutions prepared as given in the Official Methods (**7**) the order of procedure was as follows:

Two grams of the 100 mesh soil were placed in the evolution flash (Fig. 1). The apparatus was freed of atmospheric carbon dioxide by suction and then 30 cc. of 0.5 N NaOH were introduced into the absorption tower. Gentle suction was applied and 10 cc. of the oxidizing solution were run into the evolution flask. Twenty-five cc. of the acid mixture were then added, the contents gently agitated and a low flame placed under the flask. The heating was continued for 30 minutes after the mixture began to boil.

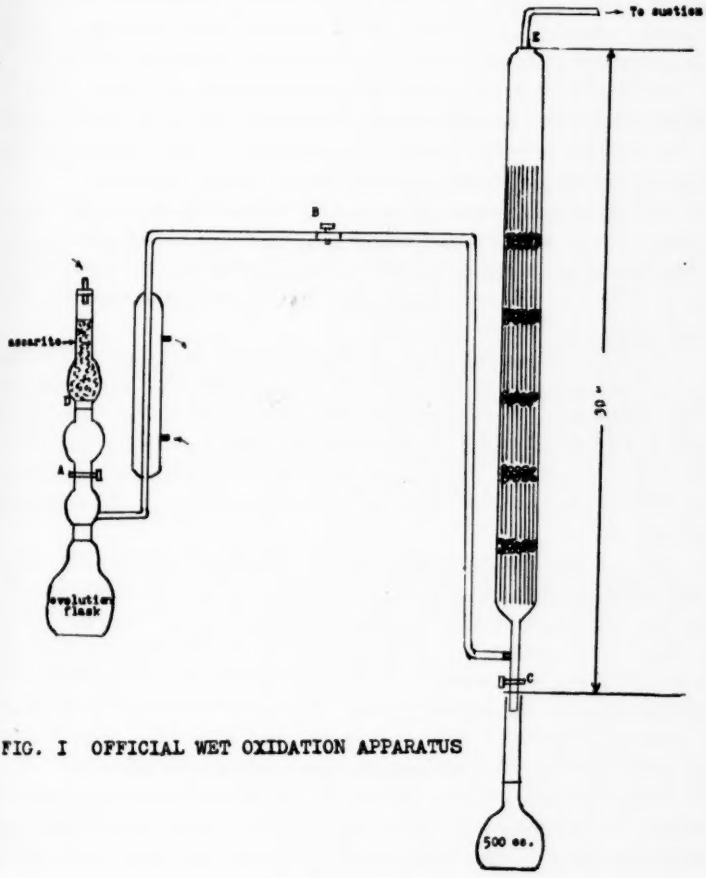

FIG. I OFFICIAL WET OXIDATION APPARATUS

The suction was released at the end of the agitation and aspiration and the absorbent was washed into a 500 cc. volumetric flask. By the addition of 10 cc. of a neutral aqueous solution of barium chloride (250 grams of $BaCl_2 . 2H_2O$ per liter) the sodium carbonate in the volumetric flask was precipitated. Then it was diluted to volume and the precipitate of barium carbonate was allowed to settle. A 200 cc. aliquot was pipeted and the residual hydroxide was titrated against 0.5 N hydrochloric acid, using phenolphthalein indicator.

The difference between the residual hydroxide in terms of 0.5 N alkali and the 0.5 N sodium hydroxide originally used is equivalent to the carbon dioxide formed by oxidation of the organic carbon plus the inorganic carbon dioxide present in the sample.

For the determination of inorganic carbon the procedure as described above was followed using the fololwing modifications: (1) 10 grams of soil were used, (2) oxidizing solution was omitted, (3) 60 cc. HC1 (1 : 9) were substituted for the acid solution. (4) The flask was agitated but not heated.

When the apparatus is set as described previously, that is: using 2 grams of soil and 30 cc. of 0.5 N sodium hydroxide in the absorption tower, it cannot determine soils which are higher than 4.498 per cent of total carbon. Soil which are higher in total carbon than the above mentioned figure need that only one gram sample should be used or else use 45 cc. of 0.5 N sodium hydroxide in the absorption tower.

Suction troubles and leakages in the rubber tubing were the principal troubles which I encountered in dealing with this apparatus. The suction must be slow and uniform otherwise the gas liberated in the reaction would pass thru the absorption tower with imperfect absorption of the gas. This may be incidental to loss of carbon dioxide and the spoiling of the determination. The suction should be arranged so that bubbling thru the absorption tower should be as constant as possible. About 30 to 50 bubbles per minute are sufficient.

When emptying the contents of the absorption tower into the 500 cc. volumetric the tower was washed 3 or 4 times with pure distilled water. After completing to volume the tower was drained thoroughly.

A strong flame while boiling was very undesirable as it forced the acid fumes in the evolution flask to pass uncondensed to the absorption tower.

The painting of rubber connections with white shellac (Devoe and Reynolds Co., Inc., N. Y.) was found to be very desirable.

Thick rubber connections were more efficient because they lasted longer in good working order than the thin-walled rubber connections.

Another precaution that was followed was to avoid the use of grease in the glass connections of the Knorr carbon dioxide apparatus.

Notwithstanding the many precautions taken to obtain the 0.5 N sodium hydroxide absolutely free of CO_2, it was found to be absolutely impossible. The presence of carbon dioxide was noticed when barium chloride was added to the alkali, in which case a very faint white precipitate was noticed. In order to see the effect of the CO_2 on the titration of the absorbent solution the following test was performed.

The 30 cc. of 0.5 N NaOH, quantity which was used for absorbing the CO_2 in the Official Method apparatus, were placed in the absorption tower. Then drained, completed to volume in the volumetric flask and finally aliquots were taken and titrated against 0.5 N HCl.

Results obtained:

Aliquot	*Titration with 0.5 N. HCl*
No. 1—200 cc.	12. cc.
100 cc.	5. 95 cc.
No. 2—200 cc.	12. 05 cc.

We might conclude then that the effect of the carbon dioxide dissolved in the alkali was negligible as far as the accuracy of the method is concerned.

II. Method of White and Holben (**14**).

The procedure as described by White and Holben (**14**) was followed as carefully as possible. The apparatus is shown in Fig. 2.

Two grams of soil were placed in the generating flask, M. Tubes F and I were connected by means of a glass tube and air was pulled through for several minutes Valve C was closed and the aspirating continued for a short time to test the apparatus and at the same time to create a partial vacuum at M. F and I were closed and the weighed tubes G and H were attached. K is detached from L and 4 grams chronic acid (CrO_3) dissolved in 10 cc. water were placed in the bulb L. K was conected to L and the solution run into flask M. Fifty cc. H_2SO_4 (sp. gr. 1.83 — 1.84) were then run into M in a similar manner leaving open valve C. Air was then pulled again thru the apparatus and the solution brought to boil. The solution was then boiled for 30 minutes during which time air was pulled through at the usual rate. Then tubes G and H. were removed, wiped, and weight after an interval of 15 minutes.

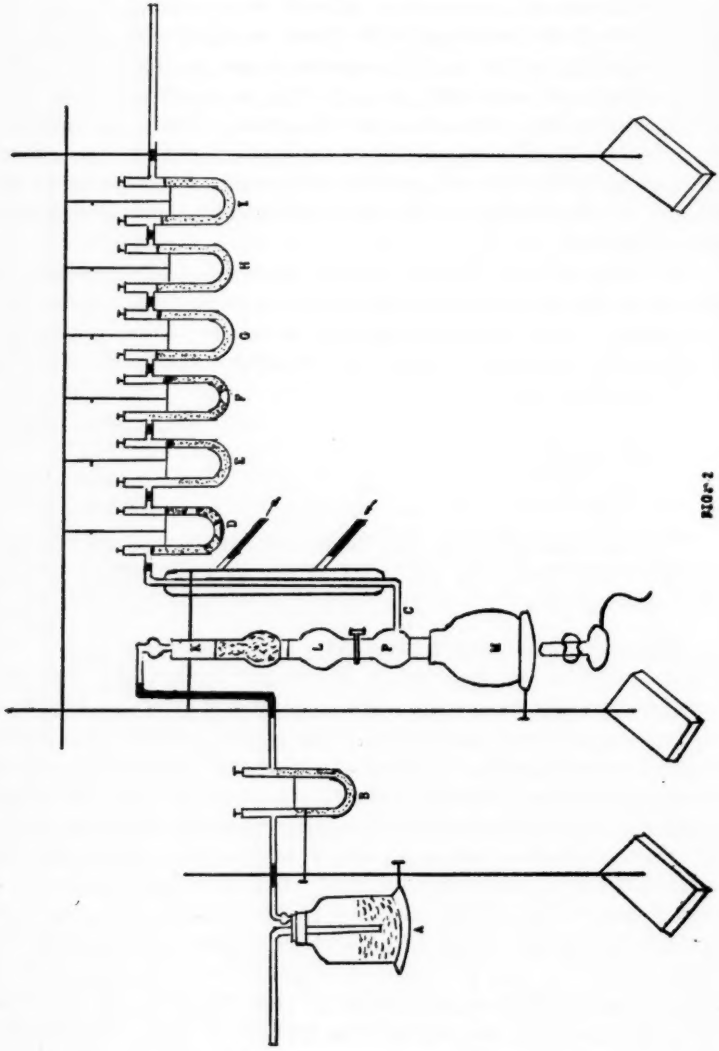

FIG. 1

Weighing of the soda-lime and acid-drying tubes required certain precautions. It was necessary to wipe the tubes and weigh them after 15 minutes in order to get equilibrium of the electrical effect created by the wiping. Tubes G and H were weighed against a common counterpoise tube of the same size made up to weight with 3 grams of the soda lime and acid-pumice tubes. Just before weighing each tube the valves were opened for an instant to equalize the inside and outside atmospheric pressures. Certain modifications of this method were tried. One of them was the substitution of ascarite absorbent for the soda-lime carbon dioxide colelcting tube. The other was the substitution of the Allihn gas-washing bottle containing 1 : 1 potassium hydroxide for ascarite in an ascarite bottle.

The results may be summarized as follows:

No. 1—Using ascarite as gas absorbent + ascarite air purifier.

Soil No.	*% Organic Carbon*
11A	1.4075
11A	1.3775

No. 2—Using soda-lime as absorbent + KOH air purifier.

Soil No.	*% Organic Carbon*
11A	1.3498

No. 3—With ascarite as CO_2 absorbent + KOH air purifier.

Soil No.	*% Organic Carbon*
3A	2.9150

No. 4—With apparatus as designed by the authors.

Soil No.	*% Organic Carbon*
3A	2.9161

From these figures we might conclude that ascarite is as good an absorbent as soda-lime and that it can be freely substituted for the soda-lime in this determination. Also a nascarite bottle is as efficient a purifier of the air as is the Allihn gas-washing bottle containing 1:1 potassium hydroxide.

After the preliminary tests the experiments were carried out in exactly the same way as described by the authors. A slight variation was made in the suctioning process in which suction from a faucet was used instead of the aspirator used by the authors. But it is supposed that this change did not affect the results of the experiments.

This gravimetric method as given by White and Holben (**14**) has certain sources of error which can only be overcome by a very care-

ful techinque. In fact any gravimetric process for the determination of carbon has decided disadvantages attending to the use of the absorption tubes. Some of the sources of error which may alter the results of this gravimetric process and which may be incident to loss of time are:

(1) It requires very elaborate precautions to prevent changes of weight of the tube due to gain or loss of moisture, necessitating complications in the purifying train and the use throughout the apparatus of drying agent of the same hygroscopic power.

(2) Difficulties in weighing large glass vessels caused by electrical effects in wiping, by buoyancy, and by changes in temperature between the balance room and laboratory.

(3) The liability to error from access of gases containing sulfur and chlorine, which may be formed during combustion of the metal or of the carbonaceous residue therefrom. The difficulty had been avoided in the chromic acid method by the use of an U tube fitted with glass beads and a saturated solution of silver sulfate in 5 per cent sulfuric acid.

(4) The difficulty of determining whether the increase in weight of the tube is due solely to the carbon dioxide.

(5) The time lost in waiting for the absorption tubes to reach equilibrium before weighing.

If the complicated purifying train gets out of order or if the tube itself introduces errors in some way, it may often be difficult to locate and correct the trouble. In actual practice with this method this last experience unfortunately occurred and it was after much working that the source of error was located in one of the U tubes whose stopper was not air tight and was thus leaking.

III. Parr's Dry Combustion Method.

The following description of the method is taken from Waterman's (**3**) thesis.

1. Place 1 gram soil, 5 gm. Na_2O_2, .75 gms. magnesium powder in the bomb, close, screw tight and explode by holding in a gas flame. Cool under tap.

2. Unscrew cap and wash charge into the 150 cc. flask, using boiling water in wash bottle. Boil the solution to remove excess oxygen and to fill the flask with water vapor.

3. While boiling the solution, raise the levelling tube till the burette is filled with mercury. Then shut stopcock. Close stopcock into acid funnel.

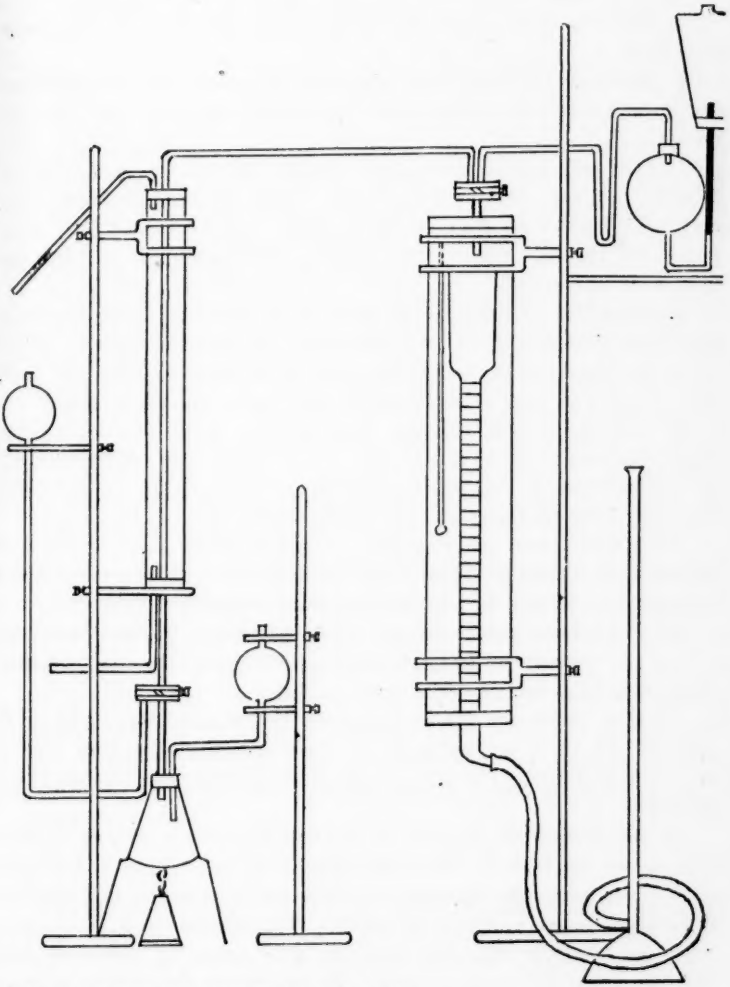

FIG. 3 PARR'S DRY COMBUSTION APPARATUS
Used by Stirling Waterman

4. Place the 150 cc. flask in place and gradually open the cock connecting the condenser with the burette. (Caution). If opened too quickly solution will boil up and pass over into burette.

5. Place 50 cc. 1:1 H_2SO_4 in acid funnel and allow to run *slowly* into flask.

6. When all H_2SO_4 is run in, close stopcock and boil solution for ten minutes controlling heat so that water will not pass into the burette.

7. Fill acid funnel with cold, recently boiled, CO_2 free, water. Allow it to run into flask until the water rises to the first stopcock. Then shut it off and connect with mercury funnel. By raising it, fill the tube right to the burette with mercury. All the gas is now in the burette.

8. Close the stopcock at the top of the burette, lower levelling tube to a convenient level and draw in air through the pipette. Then close the stopcock, raise levelling tube until both columns are level and read. The level of the KOH in the pipette should be noted.

9. Then open cock, pass gas up to 100 cc. mark into the pipette, close cock and shake to absorb the CO_2. Return the unabsorbed gas to the burette so that level of KOH is the same as in 8. Close stopcock, level the mercury and read. Difference is CO_2.

10. Again lower levelling tube as before, allow air to enter and repeat the operation. The CO_2 envolved by one gram generally requires two to five such operations—more from two grams.

11. Note temperature of gas, and barometric pressure and calculate the volume of CO_2 present at O°C and 760 mm. pressure. Then calculate the per cent total carbon.

12. The carbonate CO_2 is measured in the same way, adding 10 gms. of soil to 50 cc. water in the flask and boiling before placing on the apparatus. The rest of the operation is the same as above described.

A comparison of the Official Method and the Parr dry combustion shows the fact 14 out of 24 samples agreed within a difference of 0.2 per cent, the majority of them much more closely, and the differences being in either direction. The agreement is fairly good when we consider that the analyses were made by different individuals, using different methods. Furthermore, the samples that do not agree within a 0.2 per cent difference are pretty close to it, with the possible exception of soil 3A. The analysis of this sample by the Parr method shows a very low figure, but there is some reason to believe that something might be wrong with that figure since the other methods agreed with the expected difference.

RESULTS

COMPARISON OF 3 METHODS OF DETERMINING CARBON IN SOILS

Sample No.	Soil Type	Per cent organic carbon air-dry sample		
		Official Wet Combustion Method	Method of White & Holben	Parr's Combustion Method
16A	Ontario Loam	1.78	1.47	2.14
14A	Ontario Loam	1.85	1.67	1.69
27A	Ontario Loam	3.09	2.85	3.21
48A	Ontario Loam	1.50	1.28	1.60
57A	Ontario Loam	2.35	1.77	1.98
61A	Ontario Loam	1.65	1.38	1.65
56A	Ontario Loam	1.59	1.30	1.66
58A	Ontario Loam	1.91	1.89	2.17
7A	Volusia stony silt loam	2.55	2.27	2.86
54A	Volusia stony silt loam	5.41	4.54	5.32
34A	Volusia stony silt loam	2.79	2.45	2.32
3A	Volusia stony silt loam	3.15	2.97	2.26
49A	Volusia silt loam	1.65	1.47	1.58
12A	Volusia silty clay loam	2.67	2.45	2.74
66A	Vergennes clay	2.50	2.28	2.58
67A	Vergennes clay	2.82	2.45	2.75
65A	Vergennes clay	2.23	1.98	1.91
55A	Wooster gravelly silt loam	2.64	2.40	3.01
53A	Wooster silt loam	3.22	3.27	3.55
22A	Honeoye silt loam	2.14	1.96	2.24
32A	Dutchess silt loam	2.82	2.46	2.54
28A	Gloucester loam	2.56	2.32	2.53
11A	Dunkirk silt & clay loam	1.81	1.38	1.86
8A	Lordstown stony silt loam	3.71	3.42	3.67
63A	Worth loam	2.66	2.39	(1)

(1) Figures not available for this sample by the Parr dry combustion method.

The agreement between the methods of White and Holben (**14**) and the Parr Combustion (**13**) is not very satisfactory, the former giving uniformly low results which represent approximately 90 per cent of the total carbon obtained by the Parr method.

It would appear from these results that the official wet oxidation method is more accurate than that described by White and Holben (**14**). It appears also that the latter has the disadvantage of more complicated equipment and requires more care and time in the manipulation.

SUMMARY

1. Total carbon was determined in 25 samples of soil using the Official wet oxidation method and the chromic acid method of White and Holben (14). The results were compared with those obtained by Waterman (**13**) with the Parr dry combustion method.

2. The Official wet combustion method compared favorably with the absolute method of Parr.

The method of White and Holben (**14**) gave consistently low results.

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A MODIFICATION OF MITSCHERLICH'S METHOD FOR THE DETERMINATION OF THE NUTRIENT CONTENTS OF A SOIL

By Bernardo G. Capó.
(Graphs and Diagrams by Fernando Chardón.)

Introduction

To find the relation that exists between the concentrations of plant nutrients in a soil and the yield of the crop planted in it, has been for a long time one of the main problems tackled by agricultural chemists all the world over. Among the many investigators who have worked along this line, E. A. Mitscherlich has startled his colleagues by making a series of bold assertions with respect to this problem.

Mitscherlich's theories have been both attacked and defended with too much zeal. In fact, in many cases the scientific point of view has been overlooked, and both attackers and defenders have arbitrarily discarded data which would prove unsatisfactory for their own point of view.

To determine to just what extent Mitscherlich's theories apply to plants grown under Puerto Rican conditions and the possibility of the application of said theories to the furtherance of Puerto Rican agriculture have been objects which the author has tried to attain in complying with the requisites of the project under which this work has been performed.*

Mitscherlich's Theories

Mitscherlich has stated that the relation between the initial concentration of any given plant nutrient in a given soil and the yield of the plants grown in it may be represented by an equation of the type:

$$y = A(1 - K^x) \qquad (1)$$

where "y" is the yield of the crop obtained with the initial concentration "x" of the plant nutrient, "A" is the maximum yield obtainable with unlimited increases in the initial concentration of said plant nutrient, and "K" is a constant corresponding to the nutrient under study.

* This work has been performed under Project No. 2, Bankhead-Jones Fund.

To calculate the values of the constants "A" and "K" which are applicable to a given set of conditions, it is necessary to know at least the yields produced, under the required set of conditions, with two different initial concentrations of the plant nutrient. The corresponding values for "x" and "y" are substituted in equation (1) above, and the resulting equations are solved for "A" and "K".

If only the yields produced with two different initial concentrations of the plant nutrient are known, the substitutions will provide only two equations in the two unknowns "A" and "K". These are solved, therefore, simultaneously.

If the yields produced with more than two different initial concentrations of the plant nutrient are known, the substitutions will provide more than two equations in the two unknowns "A" and "K". These should be solved, therefore, by the Method of Least Squares in order to obtain the most probable values of the constants "A" and "K".

With the values of "A" and "K" as obtained by either of the two methods referred to above, an equation of the type of equation (1) may be written to express the relation that exists between the initial concentration of the plant nutrient and the yield of the crop which is produced in its presence under the given set of conditions. With this equation it is possible to calculate the yield of the crop which would be produced, under this set of conditions, by any initial concentration of the plant nutrient.

However, the equation which shows the relation between the initial concentration of a nutrient in a given soil, with its own set of climatic conditions, and the yield of the crop planted in it must also provide for the specific available nutrients in that soil.

The equation is therefore, modified into one of the type

$$y = A(1 - K^{b+x}) \qquad (2)$$

where "y", "A" and "K" mean the same as in equation (1), and now "b + x" is the initial nutrient concentration; "b" being the respective nutrient concentration in the unmanured soil and "x" the increase in nutrient concentration produced by the addition to the soil of materials containing said nutrient.

This equation contains, therefore, three constants or parameters whose values must be determined. In order that the values of these constants may be calculated it is necessary that at least three yields produced with three different applications of the nutrient be known.

If only three such values are known, due substitutions for "x" and "y" are made in equation (2) and the resulting three equations solved simultaneously in order to find the values of "A", "K" and "b".

If more than three yield values with the corresponding nutrient applications in whose presence they were produced are known, the substitutions in equation (2) will furnish more than three equations in these three unknowns and these equations must then be solved by the Method of Least Squares in order to obtain the most probable values of the constants "A", "K" and "b".

The value of "b" found in either of these ways is therefore the nutrient content of this soil for this respective nutrient. The application of equation (2), therefore, affords a method for the determination of the content by a soil of any given plant nutrient.

This method requires: the application to given equal amounts of soil, of three different amounts of the plant nutrient under study, the growth of a crop in each of these soil portions, the weighing of these crops, the substitution of the values of nutrient applications and corresponding crop yields for "x" and "y" respectively in equation (2), and the mathematical solution of these equations for "b".

This means that for the determination of the content by the soil of any plant nutrient, in a form as available to a given plant as the form in which the plant nutrient is used, an experiment must be performed with at least three different applications of said plant nutrient in the desired form. If it is required to determine the soil contents of the three principal nutrients, (nitrogen, phosphoric acid and potash), it is necessary that one of such experiments be performed with each of these plant nutrients, making a total of nine different treatments. Three of these treatments may be equal, reducing the total number to seven treatments. With this procedure, therefore, it is possible to calculate the soil contents of the three principal plant nutrients.

Mitscherlich has announced, however, that the constant "K" corresponding to a plant nutrient is the same for all crops and in all soils. He has stated, in fact, that the following values hold for these nutrients under all conditions, when the nutrient amounts are expressed in doublezentners per hectare:

For ammonia (NH_3):	$K = 10^{0.10}$
For phosphoric acid (P_2O_5):	$K = 10^{0.60}$
For potash (K_2O), sodium present:	$K = 10^{0.93}$
For potash (K_2O), sodium absent:	$K = 10^{0.33}$

The constancy of these "effect factors", as claimed by Mitscherlich, led him to devise a simplification of the experimental scheme described above. Since the values for the different "K's" are fixed, the determination of the soil content of a plant nutrient can be done with only two different applications of said plant nutrient, since the values of only the two parameters "A" and "b" must be found. For the study of the soil contents of all three principal nutrients a total of six different treatments would be required, which number reduces to only four different treatments, since three of the six treatments may be equal. In this way the procedure of finding the nutrient contents of a soil is very simple. If to this is added the fact that these experiments can be performed with advantage in pots, where the conditions under which all treatments act may be carefully controlled, this procedure may afford a most simple and accurate method to do these determinations. Only one requisite is lacking. That it will work. Which leads us to our experimental work, which began with some experiments designed to determine whether this simple procedure gives reliable results.

Experimental Work

To date ten different pot experiments and one field experiment have been performed in five different soil types. The field experiment was performed on a field from which a soil sample had been taken for a pot experiment. The corresponding pot and field experiments thus check one another and their results serve as indications of the reliability which may be put on the results of pot tests of the type here preferred. These two experiments are the ones which will be presented as the experimental work on which the conclusions obtained from this work have been mainly based. The results of the other pot experiments, and of a field experiment performed with eggplants at the Isabela Sub-Station farm following the plan used in our field experiment, are in line and corroborate fully the conclusions derived from the two experiments presented here.

Pot Experiment With Vega Baja Silty Clay

The Vega Baja silty clay consists of a slightly mottled alluvial gray brown top soil lying over yellow brown and red mottled stiff clay. The soil sample for this experiment was taken from field 1D

of the Station farm, where the field experiment that follows this one was established. The soil was air dried and sieved through a 0.25 inch diameter circular hole sieve. The sieved soil was well mixed and one kilogram samples taken for each pot. Mitscherlich's enameled pots with circular openings at the bottom with capacity for 6 kilogram samples were used. The one kilogram of soil for each pot was mixed with 5 kilograms of Corozos sand and with the appropriate amounts of the nutritive salts before being transferred to the corresponding pot. The Corozos sand, a white quartz type of sand, was unwashed, but rapid chemical tests showed that it contained no nitrates, nor ammonium salts, no potash and only traces of phosphoric acid. This experiment was performed with Hegari Sorghum, a crop which previous pot tests had demonstrated to be the best among a series of standard grain and grass varieties as regards germination, speed of growth and freedom from disease and insect attacks, under greenhouse conditions at the Station.

Due to the good germinating power of the seeds only 40 seeds were planted in each pot, and 35 plants were allowed to grow until harvest time. The thinning was done on the fourth day after planting, the plants being already about 1½ inches high. Due to the rapid growth of the plants, Mitscherlich's watering procedure was varied. During the first days after planting the weight of each pot was raised by 200 g. daily, later on by 100 g. daily, then by 50 g. and finally by 25 g. daily until full water capacity was reached for each pot. After the water content of a pot had been brought to full water capacity the increases in weight were reduced to only 10 grams. That is, when it was found that a pot dripped, its weight was brought with distilled water to the same weight as on the previous day. If no water had percolated to the pan beneath, the weight of the pot was raised with distilled water by 10 grams. In this way the water content of each pot was brought to full water capacity every day.

The crop was harvested when the plants were about to head, that is, at the end of the vegetative period. On harvesting, all the material above the soil in each pot was cut with shears into pieces of about 1 inch in length and placed in a tared and numbered wire basket. The plant material was then dried to constant weight in a constant temperature electric oven at a temperature of about 115°C. Constant weight was assumed to be arrived at when the basket did not lose more than 0.1 gram after being in the oven for 3 additional hours. Table I summarizes the results of this experiment.

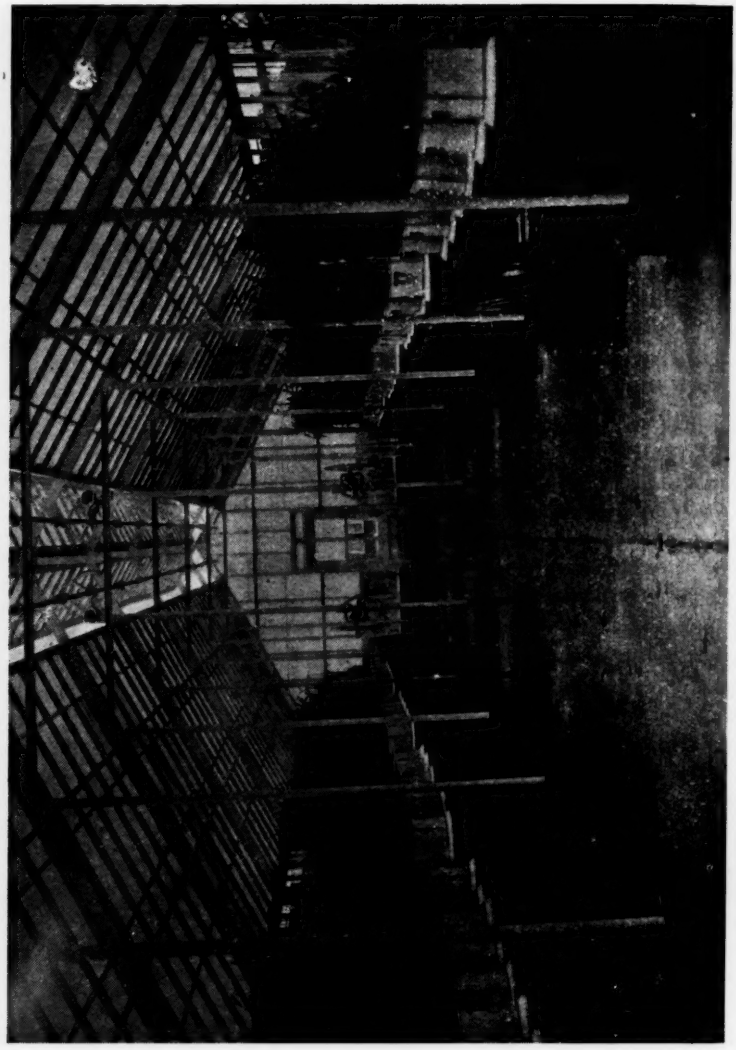


FIG. 1. Interior of the greenhouse where the pot experiment was conducted.

Treatments (in grams of substance per pot)				Yield (in grams of dry-matter per pot)				
				Replications				
No.	NH_3	P_2O_5	K_2O	1st	2nd	3rd	4th	Average
1	1.0227	0.1893	0.0000	31.0	25.6	27.9	27.0	27.9
2	1.0227	0.1893	0.1218	32.6	33.1	36.1	37.3	34.8
3	1.0227	0.1893	0.2436	43.0	40.2	37.5	42.3	40.8
4	1.0227	0.0000	0.3654	13.3	11.9	11.2	11.6	12.0
5	1.0227	0.0631	0.3654	25.3	24.3	25.9	25.8	25.3
6	1.0227	0.1262	0.3654	38.8	36.3	34.7	33.2	35.8
7	0.0000	0.1893	0.3654	10.5	10.1	10.4	10.3	10.3
8	0.3409	0.1893	0.3654	39.2	35.9	36.3	36.0	36.8
9	0.6818	0.1893	0.3654	44.1	45.0	41.5	39.4	42.5
10	1.0227	0.1893	0.3654	42.7	48.8	53.4	44.9	47.4
11	0.3409	0.0631	0.1218	20.8	21.8	21.8	21.7	21.5
12	0.6818	0.1262	0.2436	41.4	34.9	35.0	34.8	36.6

Table I.—Results of the Pot Experiment with Hegari Sorghum in Vega Baja silty clay.

Interpretation of the Results of the Pot Experiment: (*a*) The equation of the type of equation (2) above which fits best the average results obtained with treatments 1, 2, 3 and 10 is

$$y = 891.6(1 - 0.94005^{0.5163 + x}). \qquad (3)$$

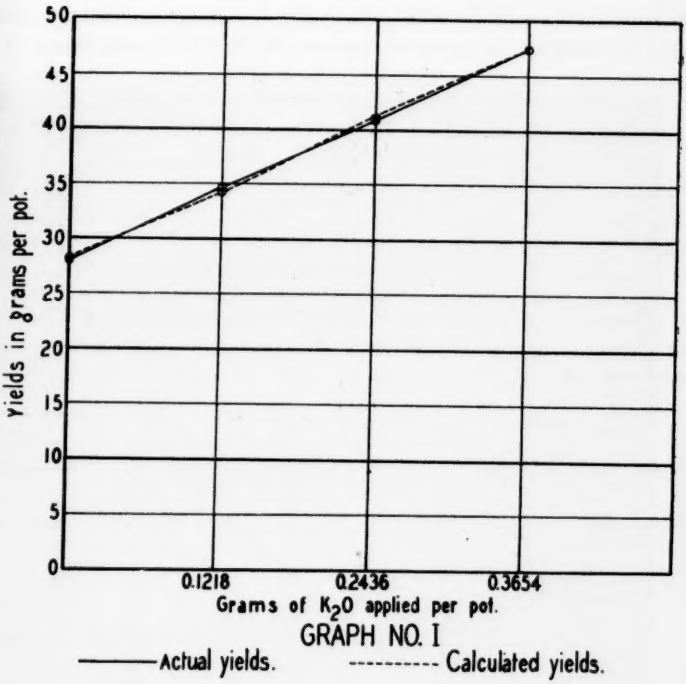
This means that in this soil there are 0.5163 g. K_2O per kilogram in a form as available to the plants as the K_2O in K_2SO_4, which was the salt used to furnish the K_2O in this experiment. The fit between th actual yields obtained and those calculated by making use of equation (3) may be observed in Table II and Graph I.

Grams K_2O added per pot	Yields (in grams of dry-matter per pot	
	Actual	Calculated
0.0000	27.9	28.1
0.1218	34.8	34.6
0.2436	40.8	41.0
0.3654	47.4	47.4

Table II.—Comparison between the average yields obtained with treatments 1, 2, 3 and 10 and those calculated by making use of equation (3).

FIG. 1. Interior of the greenhouse where the pot experiment was conducted.

FIG. 2. View, at harvest time, of pots which had received treatments 1, 2, 3 and 10 respectively.



Graph I.—Comparison between the average yields obtained with treatments 1, 2, 3 and 10 and those calculated by making use of equation (3).

The good fit obtained in this case indicates that the constants of equation (3) have values which do not differ very much from the real values and that therefore the available K_2O content of this soil is close to 0.5163 g. K_2O per kilogram of soil.

(*b*) The equation of the type of equation (2) which fits best the average results obtained with treatments 4, 5, 6 and 10 is

$$y = 1580.5(\ -0.88752^{0.0670+x}). \qquad (4)$$

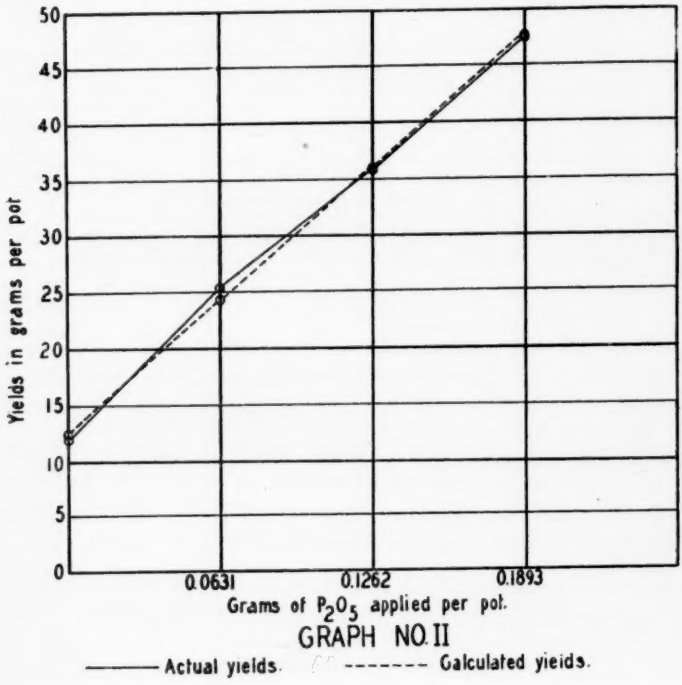
This means that in this soil there are 0.0670 g. P_2O_5 per kilogram in a form as available to the plants as the P_2O_5 in $Ca(H_2PO_4)_2H_2O$ which was the salt used to furnish the P_2O_5 in this experiment. The

FIG. 2. View, at harvest time, of pots which had received treatments 1, 2, 3 and 10 respectively.

fit between the actual yields obtained and those calculated by making used of equation (4) may be observed in Table III and Graph II.

Grams P_2O_5 added per pot	Yields (in grams of dry-matter per pot)	
	Actual	Calculated
0.0000	12.0	12.6
0.0631	25.3	24.3
0.1262	35.8	36.0
0.1893	47.4	47.6

Table III. Comparison between the average yields obtained with treatments 4, 5, 6 and 10 and those calculated by making use of equation (4).



Graph II.—Comparison between the average yields obtained with treatments 4, 5, 6 and 10 and those calculated by making use of equation (4).

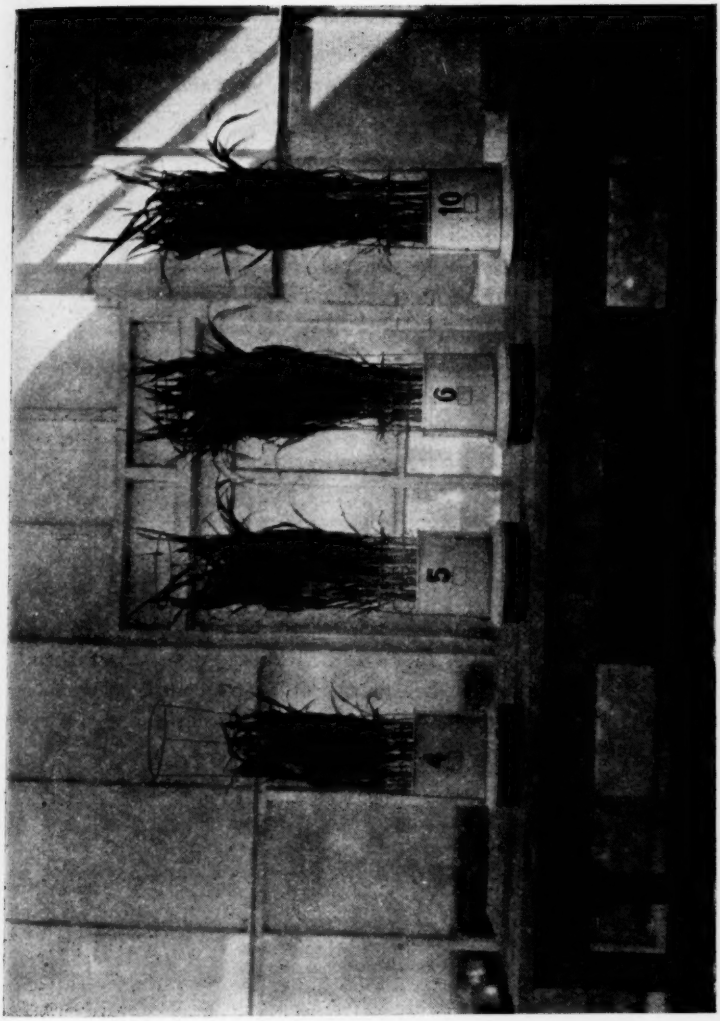


FIG. 3. View, at harvest time, of pots which had received treatments 4, 5, 6, and 10 respectively.

The good fit obtained in this case indicates that the constants of equation (4) do not differ very much from the values of the real constants and that therefore the available P_2O_5 content of this soil is close to 0.0670 g. P_2O_5 per kilogram of soil.

(*c*) The equation of the type of equation (2) which fits best the average results obtained with treatments 7, 8, 9 and 10 is

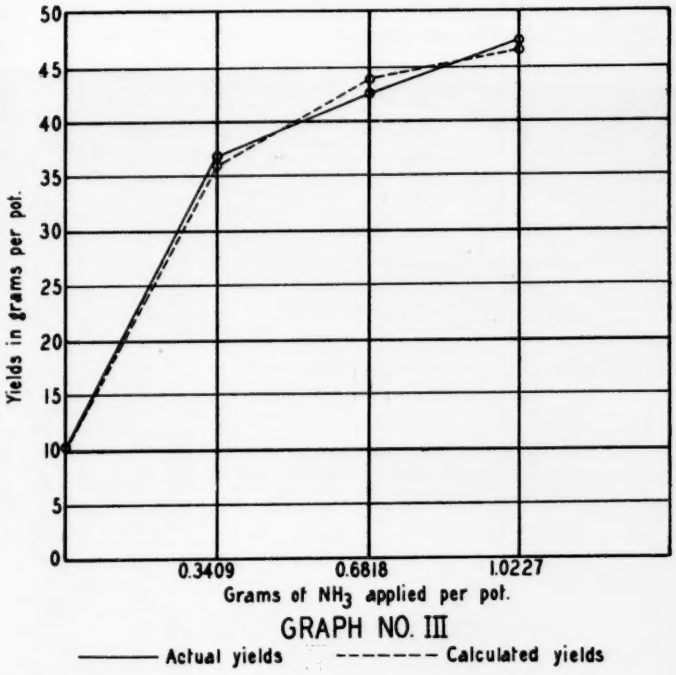
$$y = 47.53(1 - 0.0313^{0.0706+x}). \qquad (5)$$

This means that in this soil there are 0.0706 g. NH_3 per kilogram in a form as available to the plants as the NH_3 in $(NH_4)_2SO_4$ which was the salt used to furnish the NH_3 in this experiment. The fit between the actual yields obtained and those calculated by making use of equation (5) may be observed in Table IV and Graph III.

Grams NH_3 added per pot	Yields (in grams of dry-matter per pot	
	Actual	Calculated
0.0000	10.3	10.3
0.3409	36.8	38.1
0.6818	42.5	44.0
1.0227	47.4	46.5

Table IV.—Comparison between the average yields obtained with treatments 7, 8, 9 and 10 and those calculated by making use of equation (5).

The good fit obtained in this case indicates that the constants of equation (5) have values which do not differ very much from their real values and that therefore the available NH_3 content of this soil is close to 0.0706 g. NH_3 per kilogram of soil.



Graph III.—Comparison between the average yields obtained with treatments 7, 8, 9 and 10 and those calculated by making use of equation (5).

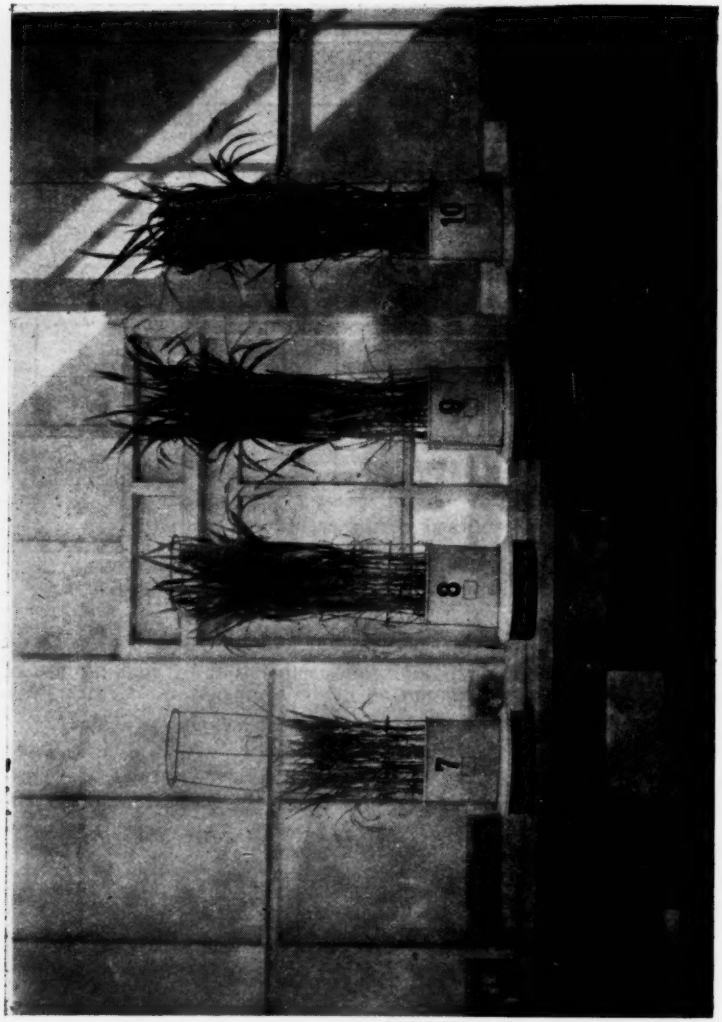


FIG. 4. View, at harvest time, of pots which had received treatments 7, 8, 9 and 10 respectively.

(*d*) Now, since according to Mitscherlich, the effect factors corresponding to the different nutritive elements are constant, it should be possible to write out a general equation relating the plant yields with the initial concentrations of these three nutrients. The general equation is of the following type:

$$y = A(1 - R_1^{b_1 + x_1})(1 - R_2^{b_2 + x_2})(1 - R_3^{b_3 + x_3}) \qquad (6)$$

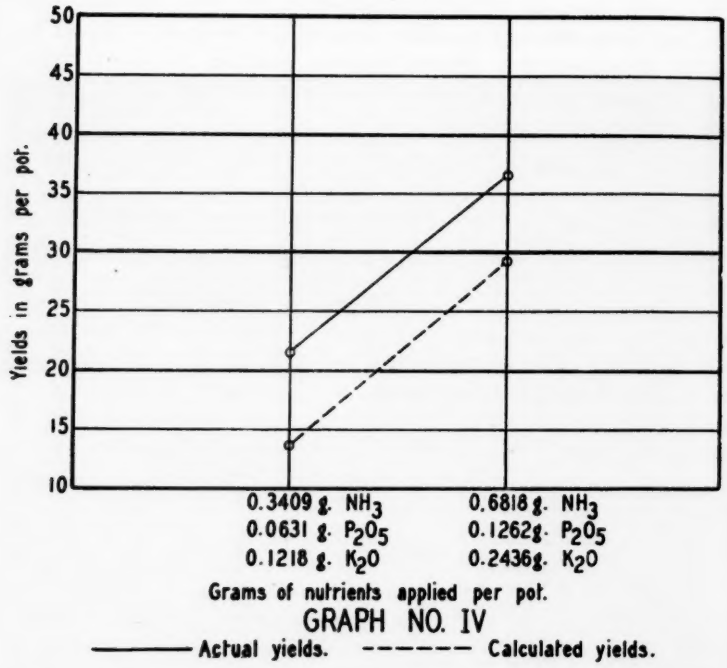
and in this particular case the calculated general equation is

$$y = 30210.2(1 - 0.0313^{0.0706 + x_n})(1 - 0.88752^{0.0670 + x_p})(1 - 0.94005^{0.5163 + x_k}) \qquad (7)$$

If Mitscherlich's assertion regarding the constancy of the effect factors were true, it should be possible to calculate with this equation the yields which would be produced with any known initial concentrations of all three plant nutrients. Treatments 11 and 12 were included in this experiment with the purpose of providing such a check. In Table V and Graph IV may be observed the fit between the actual yields obtained with treatments 11 and 12 and those calculated by making use of equation (7).

Nutrients added	Yields (in grams of dry-matter per pot)	
	Actual	Calculated
0.3409 g. NH_3; 0.0631 g. P_2O_5; 0.1218 g. K_2O	21.5	13.7
0.6818 g. NH_3; 0.1262 g. P_2O_5; 0.2436 g. K_2O	36.6	29.2

Table V.—Comparison between the average yields obtained with treatments 11 and 12 and those calculated by making use of equation (7).



Graph IV.—Comparison between the average yields obtained with treatments 11 and 12 and those calculated by making use of equation (7).

The poor fit obtained in this case indicates that equation (7) cannot be validly used for the calculation of yields produced under the conditions of the pots with treatments 11 and 12. This lack of agreement between the actual yields and those calculated by means of this equation is against Mitscherlich's affirmation with regard to the constancy of the effect factors.

Field Experiment in Vega Baja Silty Clay

This experiment was implanted on field 1D of the Station farm. The field was divided and the fertilizer treatments applied according to diagram No. 1. The manured plots, being 21.75 feet in length by 14.5 feet in width, were 1/138 acre in area. The NH_3 was applied as 25 per cent sulphate of ammonia, the P_2O_5 as 20 per cent superphosphate of lime and the K_2O as 50 per cent sulphate of potash.

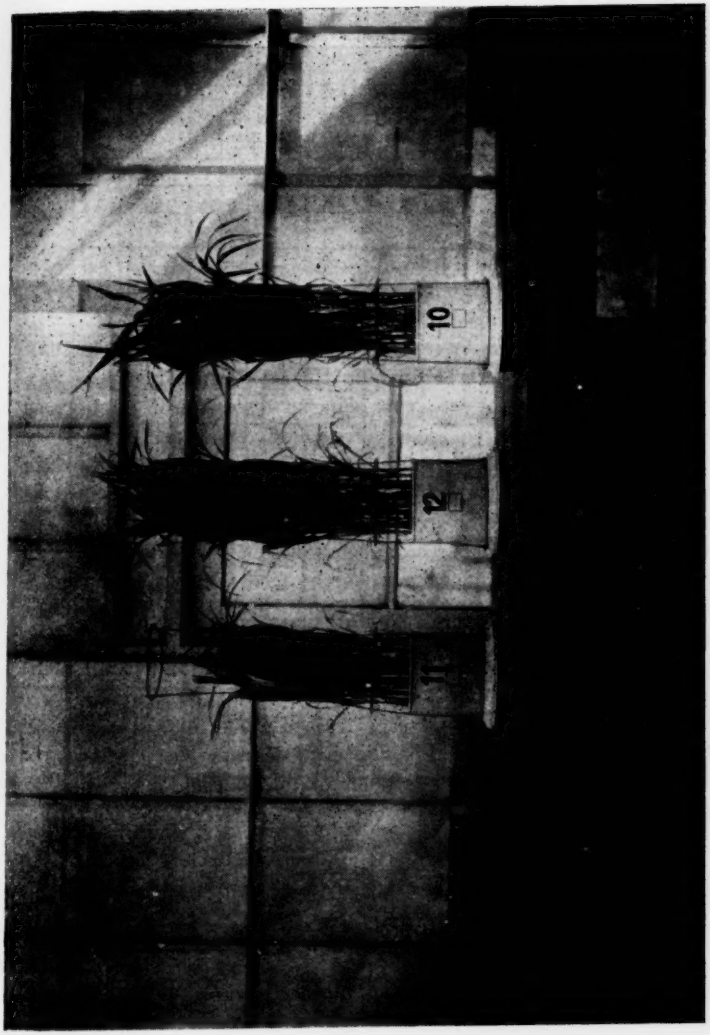


FIG. 5. View, at harvest time, of pots which had received treatments 11, 12 and 10 respectively.

The weighed salts corresponding to each plot were broadcasted uniformly over the whole surface of the plot. The treatments applied are described in Table VI.

Treatments	Cwt. NH_3 per acre	Cwt. P_2O_5 per acre	Cwt. K_2O per acre
A	2.25	2.25	0
B	2.25	2.25	0.75
C	2.25	2.25	1.50
D	2.25	0	2.25
E	2.25	0.75	2.25
F	2.25	1.50	2.25
G	0	2.25	2.25
H	0.75	2.25	2.25
I	1.50	2.25	2.25
J	2.25	2.25	2.25
K	0.75	0.75	0.75
L	1.50	1.50	1.50

Table VI.—Treatments applied in the field experiment.

Fertilizer applications were made on January 10 and 11, 1937. The field was planted several times to Hegari Sorghum in rows 34.8 inches apart, the holes in each row being at distances of 1 foot from the adjacent ones. Three seeds were planted in each hole, there being 6 rows in each plot. Due however to the repeated failures in obtaining the proper germination of the seeds, it was finally decided to plant the field to Sudan grass. The Hegari Sorghum seeds had a very high germination percentage but field 1D was infested with large numbers of ants and as soon as the seed shells were softened, the ants destroyed the seed almost completely. The Sudan grass, planted on May 6, 1937 and replanted on June 6, 1937 in the places where no seeds had germinated, gave a very good stand in all plots. The experimental field was watered almost daily for two or three weeks to insure a good stand. On August 23–4, 1937, the crop in each plot was harvested and weighed. Diagram No. I shows the distribution of the treatments on the experimental field and the yields in pounds per plot.

8-H 104.5	8-C 115.8	8-J 116.4	8-F 114.2	8-G 87.1	8-D 74.3	8-I 105.5	8-B 114.9	8-K 95.4	8-L 100.8	8-A 113.7	8-E 80.7
7-E 95.0	7-K 74.4	7-G 72.2	7-H 86.2	7-C 90.2	7-B 112.3	7-L 89.6	7-F 91.1	7-A 101.0	7-D 56.5	7-J 97.7	7-I 95.5
6-B 103.9	6-F 94.5	6-D 86.0	6-L 102.1	6-I 114.9	6-A 114.5	6-J 114.2	6-G 72.8	6-E 61.6	6-K 67.9	6-H 91.3	6-C 105.4
5-L 88.5	5-A 98.4	5-I 96.1	5-J 113.5	5-E 103.7	5-K 93.5	5-C 116.1	5-D 72.5	5-H 74.1	5-B 95.7	5-F 97.5	5-G 77.4
4-I 118.9	4-E 96.3	4-K 87.7	4-B 115.8	4-H 95.4	4-L 123.1	4-F 125.5	4-J 117.6	4-C 114.7	4-G 93.7	4-D 69.7	4-A 129.1
3-F 102.4	3-J 120.5	3-H 81.2	3-C 99.0	3-A 92.0	3-G 74.9	3-D 87.6	3-K 93.2	3-L 117.2	3-E 118.2	3-I 129.7	3-B 126.6
2-D 91.4	2-G 68.1	2-L 95.2	2-K 71.8	2-J 123.2	2-I 122.4	2-A 124.9	2-E 122.1	2-B 143.2	2-F 119.1	2-C 119.4	2-H 108.9
1-A 115.0	1-B 123.9	1-C 122.1	1-D 104.9	1-E 112.2	1-F 120.1	1-G 86.9	1-H 110.4	1-I 126.5	1-J 130.2	1-K 107.1	1-L 122.5

DIAGRAM NO. I

DISTRIBUTION OF TREATMENTS ON EXPERIMENTAL FIELD
AND
YIELDS IN LBS. PER PLOT

The results of this field experiment have been tabulated in Table VII.

Treatments (in cwt. of substance per acre)				Yields (in pounds of green material per plot)								
				Replications								Average
No.	NH_3	P_2O_5	K_2O	1st	2nd	3rd	4th	5th	6th	7th	8th	
A	2.25	2.25	0	115.0	124.9	92.0	129.1	98.4	114.5	101.0	113.7	111.1
B	2.25	2.25	0.75	123.9	143.2	126.6	115.8	95.7	103.9	112.3	114.9	117.0
C	2.25	2.25	1.50	122.1	119.4	99.0	114.7	116.1	105.4	90.2	115.8	110.3
D	2.25	0	2.25	104.9	91.4	87.6	69.7	72.5	86.0	56.5	74.3	80.4
E	2.25	0.75	2.25	112.2	122.1	118.2	96.3	103.7	61.6	95.0	80.7	98.7
F	2.25	1.50	2.25	120.1	119.1	102.4	125.5	97.5	94.5	91.1	114.2	108.0
G	0	2.25	2.25	86.9	68.1	74.9	93.7	77.4	72.8	72.2	87.1	79.1
H	0.75	2.25	2.25	110.4	108.9	81.2	95.4	74.1	91.3	86.2	104.5	94.0
I	1.50	2.25	2.25	126.5	122.4	129.7	118.9	96.1	114.9	95.5	105.5	113.7
J	2.25	2.25	2.25	130.2	123.2	120.5	117.6	113.5	114.2	97.7	116.4	116.7
K	0.75	0.75	0.75	107.1	71.8	93.2	87.7	93.5	67.9	74.4	95.4	86.4
L	1.50	1.50	1.50	122.5	95.2	117.2	123.1	88.5	102.1	89.6	100.8	104.9

Table VII.—Results of the Field Experiment with Sudan Grass on Vega Baja silty clay.

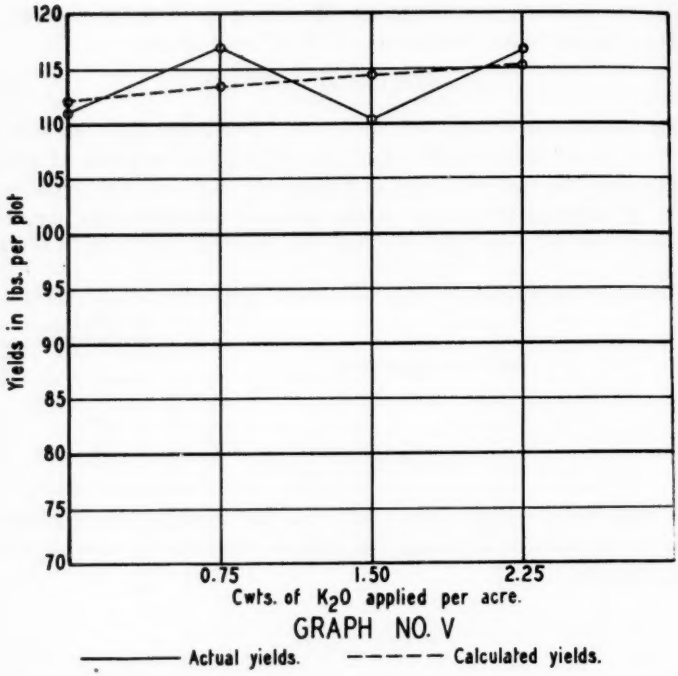
Interpretation of the Results of the Field Experiment: (*a*) The equation of the type of equation (2) which fits best the average results obtained with treatments A, B, C and J is

$$y = 120.0(1 - 0.80518^{12.61 + x}). \qquad (8)$$

This means that in this soil there are 12.61 cwts. K_2O per acre in a form as available to the plants as the K_2O in sulphate of potash which was the material used to furnish the K_2O in this experiment. The fit between the actual yields obtained and those calculated by making use of equation (8) may be observed in Table VIII and Graph V.

Cwts. K_2O added per acre	Yields (in pounds of green material per plot)	
	Actual	Calculated
0	111.1	112.2
0.75	117.0	113.4
1.50	110.3	114.4
2.25	116.7	115.2

Table VIII.—Comparison between the average yields obtained with treatments A, B, C and J and those calculated by making use of equation (8).



Graph V.—Comparison between the average yields obtained with treatments A, B, C and J and those calculated by making use of equation (8).

In the pot experiment performed with this same type of soil, it was found that the surface soil of this field contained 0.5163 g. K_2O per kilogram of soil, and if it is assumed that one acre of soil weighs 2,000,000 pounds, then it would contain 1032.6 pounds K_2O per acre. On the basis of this assumption, the field experiment demonstrates a presence of $1261/1032.6 = 1.22$ times the amount of potash determined as available by the pot experiment.

(*b*) The equation of the type of equation (2) which fits best the average results obtained with treatments D, E. F. and J is

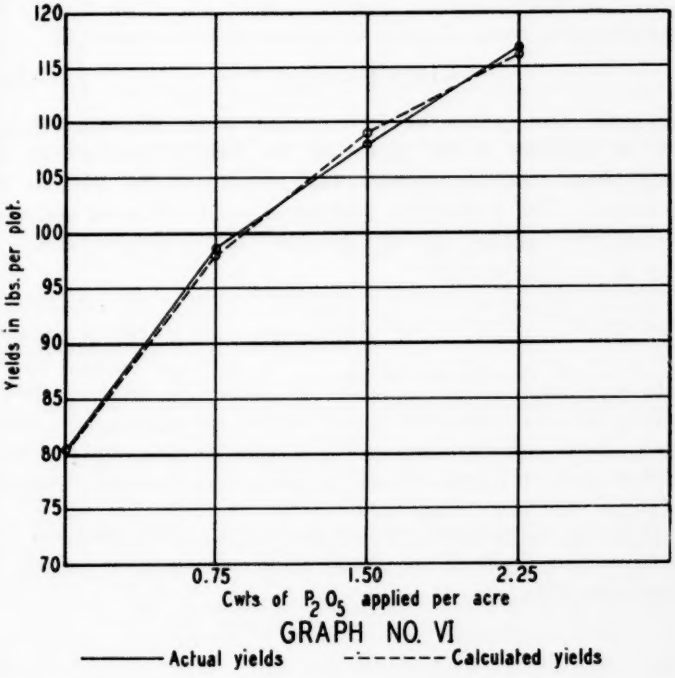
$$y = 129.0(1 - 0.55385^{1.66 + x}). \qquad (9)$$

This means that in this soil there are 1.66 cwts. P_2O_5 per acre in a form as available to the plants as the P_2O_5 in superphosphate of lime which was the material used to furnish the P_2O_5 in this experiment.

The fit between the actual yields obtained and those calculated by making use of equation (9) may be observed in Table IX and Graph VI.

Cwts. P_2O_5 added per acre	Yields (in pounds of green material per plot)	
	Actual	Calculated
0	80.4	80.6
0.75	98.7	97.9
1.50	108.0	109.1
2.25	116.7	116.2

Table IX.—Comparison between the average yields obtained with treatments D, E, F and J and those calculated by making use of equation (9).



Graph VI.—Comparison between the average yields obtained with treatments D, E, F and J and those calculated by making use of equation (9).

In the pot experiment performed with this same type of soil it was found that the surface soil of this field contained 0.0670 g. P_2O_5 per kilogram of soil, and if it is assumed that one acre of soil weighs 2,000,000 pounds, then it would contain 134 pounds P_2O_5 per acre. On the basis of this assumption, the field experiment demonstrates a presence of $166/134 = 1.24$ times the amount of P_2O_5 determined by the pot experiment. This figure compares favorably with the previous one of 1.22 obtained in the case of K_2O as the variable factor. The ratio of the amounts of P_2O_5 and K_2O determined by the pot experiment is practically equal to the ratio of the amounts of P_2O_5 and K_2O determined by the field experiment. This may be considered a good check with regard to the accuracy of this kind of pot experiments.

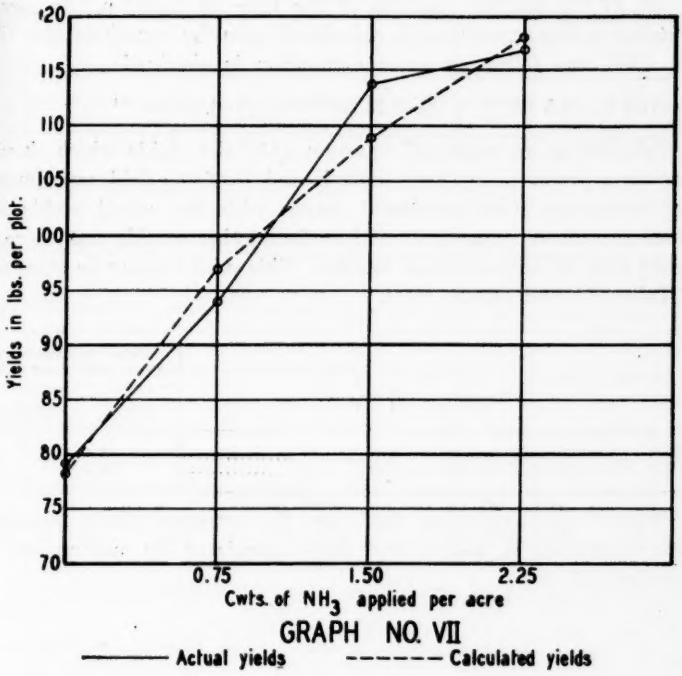
(*c*) The equation of the type of equation (2) which fits best the average results obtained with treatments G, H, I and J is

$$y = 136.6(1 - 0.5968^{1.65 + x}). \qquad (10)$$

This means that in this soil there are 1.65 cwts. NH_3 per acre in a form as available to the plants as the NH_3 in sulphate of ammonia which was the material used to furnish the NH_3 in this experiment. The fit between the actual yields obtained and those calculated by making use of equation (10) may be observed in Table X and Graph VII.

Cwts. NH_3 added per acre	Yields (in pounds of green material per plot)	
	Actual	Calculated
0	79.1	78.3
0.75	94.0	97.0
1.50	113.7	109.0
2.25	116.7	117.9

Table X.—Comparison between the average yields obtained with the treatments G, H, I and J and those calculated by making use of equation (10).



Graph VII.—Comparison between the average yields obtained with the treatments G, H, I and J and those calculated by making use of equation (10).

In the pot experiment performed with this same type of soil, it was found that the surface soil of this field contained 0.0706 g. NH_3 per kilogram of soil, and if it is assumed that one acre of soil weighs 2,000,000 pounds, then it would contain 141.2 pounds NH_3 per acre. On the basis of this assumption, the field experiment demonstrates a presence of $165/141.2 = 1.17$ times the amount of NH_3 determined by the pot experiment. This figure is of the same order as the two previous ones found with K_2O and P_2O_5 as nutrients in variable amounts and it seems as if it might be concluded, in the light of this evidence, that pot experiments of this type may be used to determine with fair accuracy the relative available amounts of the three principal nutrients, i. e., nitrogen, phosphoric acid, and potash.

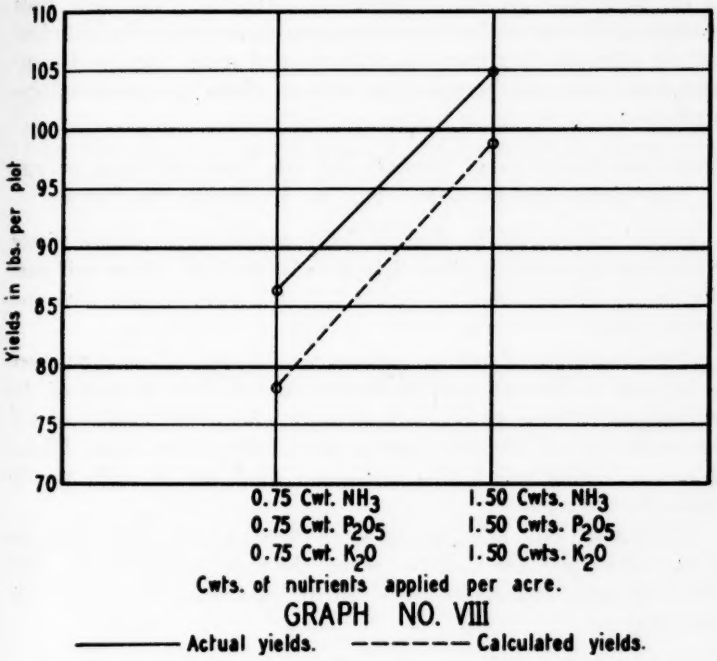
(*d*) If the general equation of the type of equation (6) corresponding to this experiment is calculated from the equations (8), (9) and (10), the following general equation is obtained:

$$y = 153.6(1-0.5\ 68^{1.65+x_n})(1-0.55385^{1.66+x_p})(1-0.80518^{12.61+x_k}). \quad (11)$$

Calculating by means of equation (11) the yields which should have been produced by treatments K and L of the field experiment, and comparing these calculated values with the actual yields obtained in said experiment, it will be found that in this case there is a very poor fit between these results. This poor fit may be observed in Table XI and Graph VIII.

Nutrients added per acre	Yields (in pounds of green material per plot)	
	Actual	Calculated
0.75 cwt. NH_3; 0.75 cwt. P_2O_5; 0.75 cwt. K_2O	86.4	78.2
1.50 cwt. NH_3; 1.50 cwt. P_2O_5; 1.50 cwt. K_2O	104.9	98.8

Table XI.—Comparison between the average yields obtained with treatments K and L and those calculated by making use of equation (11).



Graph VIII.—Comparison between the average yields obtained with treatments K and L and those calculated by making use of equation (11).

This behaviour is analogous to the one observed in the case of the pot experiment and it corroborates a conclusion which might have been drawn from those results, in fact, that the general equation calculated for a crop growing in a soil under certain fertilizer concentrations is not applicable to other conditions. This same behaviour was noticed by the late W. J. Spillman on studying the results of a tobacco fertilizer experiment conducted by W. W. Garner and his associates at Georgia. The explanation for these discrepancies offered by Spillman might be accepted for said experiment but in our case, where the conditions claimed to produce those effects were not present, no explanations of this sort are possible to maintain the general applicability of such an equation. If this is so, then, the 4-treatment procedure recommended by Mitcherlich, based on the applicability of this general equation and with fixed values for the effect factors, shonld not give reliable results.

The conclusion arrived at, therefore, is that the 7-treatment tests should be preferred to the 4-treatment ones recommended by Mitscherlich, for although they are more elaborate and costly than the 4-treatment ones, yet their accuracy more than offsets the disadvantages mentioned.

Procedure Followed at Present for the Determinarion of the Nutrient Contents of a Soil by Means of Pot Tests

Partial samples to the desired depth are taken at several places in the field representing the soil type to be studied. These soil samples are air dried, sieved through a 0.25 inch circular hole sieve and well mixed.

The proportion of soil to Corozos sand in the soil-sand mixture to be used in the pot tests is determined from the texture of the soil sample. For example, with clays or silty clays 2 kilos of soil are mixed with 4 kilos of Corozos sand, with sandy loams 4 kilos of soil are mixed with 2 kilos of Corozos sand, etc., to make up the 6 kilos for each pot.

The soil and sand are mixed in an oil cloth with the proper amounts of the salts which are used to furnish the nutritive materials. The following seven treatments are given by quadruplicate to each soil-sand mixture:

1—1.000 g. NH_3; 1.000 g. P_2O_5.
2—1.000 g. NH_3; 1.000 g. P_2O_5; 0.500 g. K_2O.
3—1.000 g. NH_3; 1.000 g. K_2O.
4—1.000 g. NH_3; 0.500 g. P_2O_5; 1.000 g. K_2O.
5—1.000 g. P_2O_5; 1.000 g. K_2O.
6—0.500 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O.
7—1.000 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O.

Of the 28 pots used to study each soil: treatment 1 is given to pots Nos.. 1, 8, 15 and 22; treatment 2 is given to pots Nos. 2, 9, 16 and 23; treatment 3 is given to pots Nos. 3, 10, 17 and 24; treatment 4 is given to pots Nos. 4, 11, 18 and 25; treatment 5 is given to pots Nos. 5, 12, 19 and 26; treatment 6 is given to pots Nos. 6, 13, 20 and 27; and treatment 7 is given to pots Nos. 7, 14, 21 and 28.

Once the soil, sand and salts corresponding to a given pot are well mixed, the whole mixture is transferred to the corresponding Mitscherlich's pot. Each pot is weighed and is then ready to plant.

Immediately before planting, 400 ml. of distilled water are poured on top of the soil of the pot with a sprinkler. With the Hegari Sorghum seeds now available, 40 seeds are planted in each pot with

the idea of leaving 35 plants to grow in each pot. The seeds are half-buried, by using a small forceps. The seeds are distributed uniformly upon the whole surface of the pot. A rapid and easy way to do this distribution is to plant the first 37 seeds in the order illustrated in diagram No. 3, turning the pots around after planting seed No. 22. The other three seeds are planted to fill the largest vacant spaces remaining after the first 37 seeds are planted.

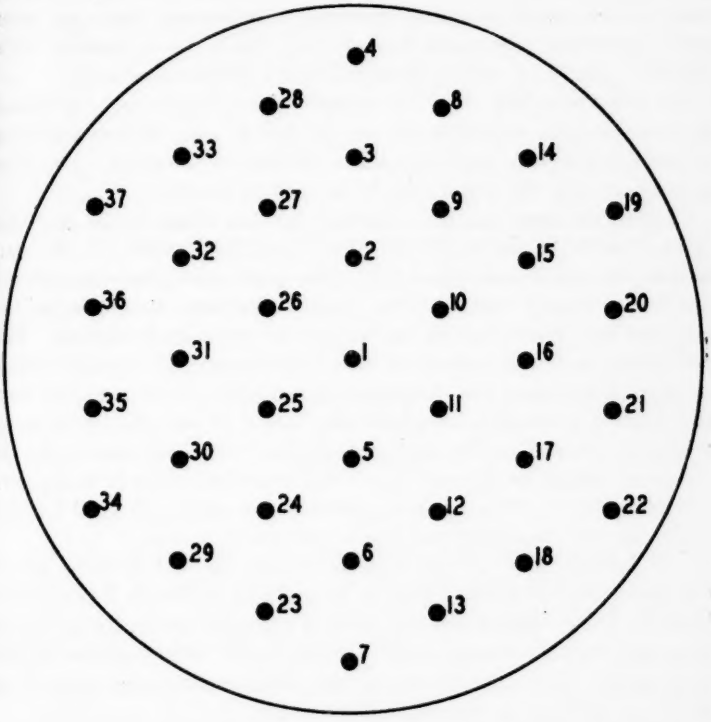


DIAGRAM NO. II

MANNER OF PLANTING SEEDS IN ORDER TO OBTAIN A UNIFORMLY SPACED DISTRIBUTION.

After the 40 seeds have been half-buried, drops of water are allowed to fall over and around the seeds in order to pack the soil against the seeds but leaving their upper part uncovered.

The next day nearly all the seeds will have broken their shells. The seeds which have loosened themselves are half-buried again and the whole surface of the pot is moistened.

This procedure is repeated the next day, by which time the seeds will have sent their first root into the soil and their shoots will be about ½ inch in height.

On the next day most of the plants will have already 2 leaves open and they will be about 1½ inches in length. The ungerminated seeds and as many plants as necessary are removed this day from each pot, leaving 35 plants in each pot. Each pot is brought with distilled water to a weight equal to its dry weight plus 800 g.

In the succeeding days the water content of the pots is raised by increasing the weight of the pots by 200 g. daily at first and then by smaller amounts until full water capacity is attained. The idea is to attain this full water capcity as soon as possible.

After this stage has been reached the first thing in the morning to be done is to see which pots have percolated water to the pan below and which ones have not. The pots which have percolated water are brought with distilled water to the same weight as on the previous day, after pouring on the pot the percolated solution. The pots which have not percolated water are brought to a weight which is 10 g. larger than the corresponding weights of the previous day. However, if after thus increasing the weight of one pot by 10 g. on a day it is found on the next day that no water percolates, the increase in weight on the next day (and succeeding ones if necessary) will be by 20 g. This watering procedure is continued until harvest time; in our case, until the plants are about to head.

At harvest time all the material above the soil in each pot is cut into pieces of about 1 inch in length and placed in a tared wire basket. These baskets are placed on a constant temperature electric oven and kept at a temperature of about 115°C. until constant weight is attained. It is usually found that this condition is attained on allowing the oven to stay lighted overnight.

The baskets are weighed on a torsion balance to the nearest 0.1 gram immediately upon removing from the oven, the procedure being to remove one tray and weigh it before removing the next.

The calculations necessary to do the interpretation of one of these experiments are presented below. This experiment was performed with Río Piedras clay, a very acid type of soil (pH — 4.39) in which a previous experiment done without $CaCO_3$ applications had failed due to the extreme acidity of this soil. For this reason, $CaCO_3$ as a variable factor was also introduced in this experiment, making a

total of 9 treatments instead of the standard number of 7 treatments. The treatments and yields obtained are found in Table XII. In this case 2 kilos of soil were mixed with 4 kilos of Corozos sand.

Treatments		Yields (in grams per plot)				
		Replications				
No.	Nutrients added per pot	1st	2nd	3rd	4th	Average
1.....	1.000 g. P_2O_5; 1.000 g. K_2O; 6.000 g. $CaCO_3$.....	19.0	18.2	17.5	17.8	18.125
2.....	0.500 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O; 6.000 g. $CaCO_3$.....	34.7	33.6	33.6	33.6	33.875
3.....	1.000 g. NH_3; 1.000 g. K_2O; 6.000 g. $CaCO_3$.....	7.1	7.1	7.7	7.2	7.275
4.....	1.000 g. NH_3; 0.500 g. P_2O_5; 1.000 g. K_2O; 6.000 g. $CaCO_3$.....	30.5	32.4	29.9	30.0	30.700
5.....	1.000 g. NH_3; 1.000 g. P_2O_5; 6.000 g. $CaCO_3$.....	23.3	22.3	19.8	22.9	22.075
6.....	1.000 g. NH_3; 1.000 g. P_2O_5; 0.500 g. K_2O; 6.000 g. $CaCO_3$.....	31.8	36.7	34.1	32.2	33.700
7.....	1.000 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O.....	6.0	8.1	6.3	5.8	6.550
8.....	1.000 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O; 3.000 g. $CaCO_3$.....	30.9	33.6	31.1	31.8	31.850
9.....	1.000 g. NH_3; 1.000 g. P_2O_5; 1.000 g. K_2O; 6.000 g. $CaCO_3$.....	34.6	36.0	32.9	35.5	34.750

TABLE XII. Results obtained in a fertilizer pot experiment with Rio Piedras clay.

The following formulas, derived from equation (2), are used to simplify the calculation processes:

$$R = \frac{y_3 - y_2}{y_2 - y_1} \tag{12}$$

$$M = \frac{y_2 - y_1}{R^{x_1} - R^{x_2}} \tag{13}$$

$$A = y_1 + MR^{x_1} \tag{14}$$

$$b = \frac{\log M - \log A}{\log R} \tag{15}$$

To calculate the amount of available NH_3 in the 2 kilos of soil used for the soil-sand mixture, the average yields of treatments 1, 2 and 9 are used. Thus, expressing the NH_3 aplications as units of 0.500 g. NH_3 to simplify the calculations.

$x_1 = 0$; $y_1 = 18.125$
$x_2 = 1$: $y_2 = 33.875$
$x_3 = 2$; $y_3 = 34.750$

Therefore, $R = \frac{34.750 - 33.875}{33.875 - 18.125} = \frac{0.875}{15.750} = 0.05556$

$$M = \frac{15.750}{1 - 0.0556} = \frac{15.750}{0.944444} = 16.6765$$

$$A = 18.125 + 16.6765 = 34.8$$

$$b = \frac{1.22210 - 1.54158}{0.74476 - 2} = \frac{-0.31948}{-0.25524} = 0.2545 \text{ units or}$$

0.2545(0.500 g. NH_3)=0.1272 g. NH_3. Therefore, this soil contains 0.1272 g. NH_3 per 2 kilos of soil.

The calculation of the available amounts of the other nutrients is made in a similar way.

Summary and Conclusions

A discussion of the principles underlying the applications of Mitscherlich's equations to the determination of the nutrient contents of a soil and of the objects in view in complying with the requisites of the project under which the described studies were done have been made.

The procedure employed in performing a certain pot experiment with Mitscherlich's pots is described. A detailed interpretation of the results of that experiment has been made.

The procedures used in performing and in the interpretation of the yield data obtained from a field experiment implanted on a field with the same soil type as was used in the pot experiment have been also described. The results of both of these experiments have been compared and the conclusions set further on have been derived from the results obtained in this comparison.

Detailed instructions for making the determination of the nutrient contents of a soil by a modification of Mitscherlich's 4-treatment method are presented.

The following conclusions are derived from the experimental data presented:

1. Mitscherlich's special equation for the relation existing between the initial nutrient concentration of a single nutrient in a soil and the yield of a crop there planted is an accurate and simple one.

2. Such an equation may be used to determine with a high precision the available amount of any nutrient in a given soil.

3. Mitscherlich's general equation relating the yield of a crop with the initial concentrations of the three principal nutrients, (nitrogen, phosphoric acid and potash), does not hold.

4. Mitscherlich's 4-treatment method, based on the applicability of this latter equation, is not accurate under Puerto Rican conditions for the vegetative period of growth of a crop, that is, from the time of planting to the time of heading.

5. A modification of Mitscherlich's method, including 7 treatments and based on the applicability of the Mitscherlich's special equations for variations in the concentrations of each individual nutrient respectively, is described as now used.

Acknowledgments

The author wishes to express his profound gratitude to Mr. Fernando Chardón, Assistant Sugar-Cane Specialist, for his invaluable cooperation by drawing the graphs and diagrams with which this article has been illustrated. He also desires to make known his everlasting sympathy and appreciation to Mr. Juan Amedée Bonnet, Soils Expert, who as leader of the project under which the work outlined was done, cooperated whole-heartedly to its progress, and who had the courtesy and benevolence to aid with valuable suggestions for the correction of the galley proofs of this article.

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NEW SOUTH AMERICAN SARCOPHAGIDAE (DIPTERA)

By DAVID G. HALL, Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, Washington, D. C.

The following species of Sarcophagidae are described in order to make the names available for Mr. L. F. Martorell, of the Puerto Rican Experiment Station at Río Piedras, who collected the specimens.

Sarcophaga camura, new species

Figure 1

Male.—Head with front narrow, 0.18 of head width; parafacial and parafrontal silvery pollinose, with a slight yellowish tinge, the former bare; frontal bristles about eight or nine, the rows not widely diverging below, and descending about to the base of the second antennal segment; reclinate fronto-orbital bristles absent; ocellar bristles minute, outer vertical bristles not differentiated; antenna rather yellowish, third segment nearly three times length of second and reaching nearly to vibrissae, which are normal and at oral margin; clypeus long and narrow; epistoma short and hardly narrowed; arista with long plumosity; palpus and proboscis black, both ordinary; bucca short, less than one-fifth eye height, and with both black and pale yellowish-brown hairs before the metacephalic suture; back of head with one row of postocular ciliae and with pale hairs below.

Thorax silvery pollinose, with the normal three to five black stripes; propleura bare; anterior acrostichal bristles absent; anterior dorsocentral bristles two; humeral bristles two; posterior dorsocentral bristles three; sternopleural bristles two; prescutellar bristles present but reduced; laterally and below with long, yellowish-brown hairs; scutellum with three marginal bristles and without preapical or apical bristles.

Abdomen tessellated and with three shifting black stripes; median marginal bristles on both second and third visible segments; fourth visible segment with a marginal row of about 12 bristles; laterally and below with long yellowish-brown hair.

Hypopygium of normal size; first segment black and heavily grayish pollinose; second segment smaller than first, black, with abundant, long, curling, black hairs; genital features as illustrated.

Wing hyaline; costal spine absent; third costal section about as long as fifth; first and fifth veins bare; third vein with some basal setulae; basicosta yellow.

Legs black; fore and middle femora distally and below with some long yellowish-brown hairs; middle tibia with one anterodorsal bristle and some villosity; hind femur and tibia with long villosity.

Female.—Unknown.

Type locality.—"La Providencia", Maracay, Venezuela.

Type and *paratype.*—U. S. National Museum No. 52069.

Remarks.—Described from the type and one male paratype collected November 13, 1932, by Serres and Martorell.

The peculiar elongate yellowish-brown pile or hair on the sternum and venter in this species approaches the condition found in Sarothromyinae. This species runs to *Mehria* End. in Townsend's keys, 1935, Manual of Myiology, *2,* but is not closely related to *Sarcophaga nemoralis* Kr., the genotype of *Mehria,* which is European. I describe it in the genus *Sarcophaga* sens. lat. until additional related material can be studied.

Sarcophaga rimosa, new species

Figure 2

Male.—Head with front very narrow, only 0.14 of head width; one parafrontal only one-third width of frontal stripe; parafrontal and parafacial bright golden pollinose, the pollinosity becoming thinner toward vertex; facio-orbital bristles present in several rows below, near eye; frontal bristles about 14, the rows widely diverging below and extending to about the middle of the second antennal segment; inner vertical bristles present; vibrissae considerably above oral margin and slightly approximated, bucca about one-fourth eye height, with only black hair before the metacephalic suture; back of head with one and a partial second row of postocular ciliae.

Thorax black, with six yellowish, dorsal, longitudinal stripes, two median, two postsuturally extending over the postalar callus, and two extending over the humeri and notopleurae to the postalar callus; a golden pleural stripe extending across the propleura, metapleura, and pteropleura; anterior acrostichal bristles three; posterior acrostichal bristles three or four; anterior dorsocentral bristles three; posterior dorsocentral bristles four; sternopleural bristles three; scutellum black with golden pollen, except for a median longitudinal stripe, with two marginal bristles, one subapical bristle, and one apical bristle.

Abdomen black, tessellated, with four rows of golden pollinose spots, these spots not extending to the posterior margins of the segments; third segment with median marginal bristles; fourth segment with a marginal row of about 12 bristles; fifth sternite reddish-orange, the two arms widely diverging and with long, thin hairs along the inner margins.

Hypopygium of normal size; first segment red; second segment globose, smaller than first, red, with long, curling, black hairs. Genital features as illustrated.

Wing hyaline, third costal section as long as fifth; third vein with several basal setulae.

Legs black; anterior tibia with one posterior bristle at apical third; mid femur with two posterior bristles near apex; mid tibia with one anterodorsal bristle at apical third; hind tibia without long villosity.

Female.—Unknown.

Type locality.—"La Providencia", Maracay, Venezuela.

Type.—U. S. National Museum No. 52071.

Remarks.—This species appears to some extent like species of *Orobrachycoma* Tns., which differ by having three posterior dorso-central bristles; also like species of *Dexosarcophaga* Tns., which differ by having the hypopygium red and the second segment of the abdomen with median marginal bristles.

Abacantha, new genus

Male.—Head without parafacio-orbital bristles; frontal bristles about seven, the rows hardly divergent below; one proclinate fronto-orbital bristle and one reclinate fronto-orbital bristle; outer vertical bristle distinct; third antennal segment fully four times as long as second and reaching almost to the vibrissae, which are normal and at the oral margin; bucca short, less than one-fourth eye height.

Thorax without anterior acrostichal bristles; posterior dorso-central bristles two; sternopleural bristles three; prescutellar acrostichal bristles present.

Abdomen with median marginal bristles on the third segment.

Wing hyaline; first vein setulose.

Legs: Mid femur with comb; hind tibia without villosity.

Genotype.—*Abacantha zygox*, new species.

Abacantha zygox, new species

Figure 3

Male.—Head with front 0.29 of head width; parafrontals and parafacials golden pollinose; antenna black; palpus and proboscis black, both ordinary; bucca with only black hair before the metacephalic suture; back of head with two rows of postocular ciliae, around the middle and below with but pale hair.

Thorax silvery-gray pollinose, with the normal three to five black stripes; scutellum with three marginal bristles and one apical bristle.

Abdomen tessellated and with three shifting black stripes; fourth segment black to apex and with a marginal row of about 12 bristles. Fifth sternite yellow-orange, the inside margins of the two divergent arms covered with soft yellowish pile.

Hypopygium with the first segment red, darker at base and without the customary row of marginal setae; second segment red, small, retracted. Genital features as illustrated.

Wing without costal spine, third costal segment about as long as fifth; third vein with some basal setulae.

Legs black, mid tibia with one anterodorsal bristle.

Type locality.—"La Providencia", Maracay, Venezuela.

Type and *paratype.*—U. S. National Museum No. 52072.

Remarks.—Described from the holotype male, collected by Martorell, and one paratype male collected at San Mateo, Costa Rica, by Pablo Schild, dates unknown.

This species appears close to species belonging to *Notochaeta* Aldrich, having but two posterior dorsocentral bristles. The setulose first vein is suggestive of *Micronotochaeta* Townsend but the head shape of this genus is different. I have not seen specimens of *Anaravinia* Tns., but this genus lacks the ctenidium on the mid femur. *Catheronychia* Tns. is composed of much smaller species, all of which have three posterior dorsocentral bristles.

Tripanurga albicans (Wiedemann)

Figure 4

Sarcophaga albicans Wied., 1830, Auss. Zweifl. *2*, p. 363.
Tripanurga albicans (Wied.), Br. & Berg. 1891, Zweifl. Kais. Mus. *5*, p. 363.

The following description is given to supplement the inadequate descriptions published heretofore.

Male.—Head with front 0.3 of head width; parafrontals and parafacials silvery-gray pollinose, the latter with a row of facio-orbitals below near eye; frontal bristles about six, the rows slightly converging below and reaching to the antennal insertion; proclinate fronto-orbital bristles one; reclinate fronto-orbital bristles one; outer vertical bristles present; antenna black, third segment at least three times as long as the second and reaching almost to the vibrissae, which are normal and at the oral margin; aristal plumosity normal; palpus and proboscis black, both ordinary; bucca one-third the eye height and with only black hair before the metacephalic suture; back of head with one defined row of post-ocular ciliae, around the middle and below with some pale hair.

Thorax silvery-gray pollinose and with the normal three to five black stripes; anterior acrostichal bristles absent; anterior dorso-central bristles two; posterior dorso-central bristles four; sternopleural bristles two; presutellar acrostichal bristles present; scutellum with two marginal bristles and one preapical bristle.

Abdomen tessellated and with three shifting black stripes; median marginal bristles on the third segment only; fourth segment with a marginal row of about 10 bristles. The posterior part of the abdomen is enlarged and deepened for the reception of the large hypopygium.

Hypopygium with the first segment black, dusted with gray pollen and with a marginal row of about 10 setae; second segment smaller, black, with whitish pollen. Genital features as illustrated.

Wing hyaline; third costal segment as long as fifth, third vein with several setulae at base; first vein setulose.

Legs black; middle tibia with two anterodorsal bristles.

Female.—With two proclinate fronto-orbital bristles and the abdomen of normal shape and depth, otherwise as in male except for normal sexual differences.

Remarks.—The type locality of this species is Brazil, and all of the previous material I have seen has been Brazilian. It is therefore interesting that Serres and Martorell collected one male and one female of the species on November 13, 1932, at "La Providencia", Maracay, Venezuela.

Explanation of Figures

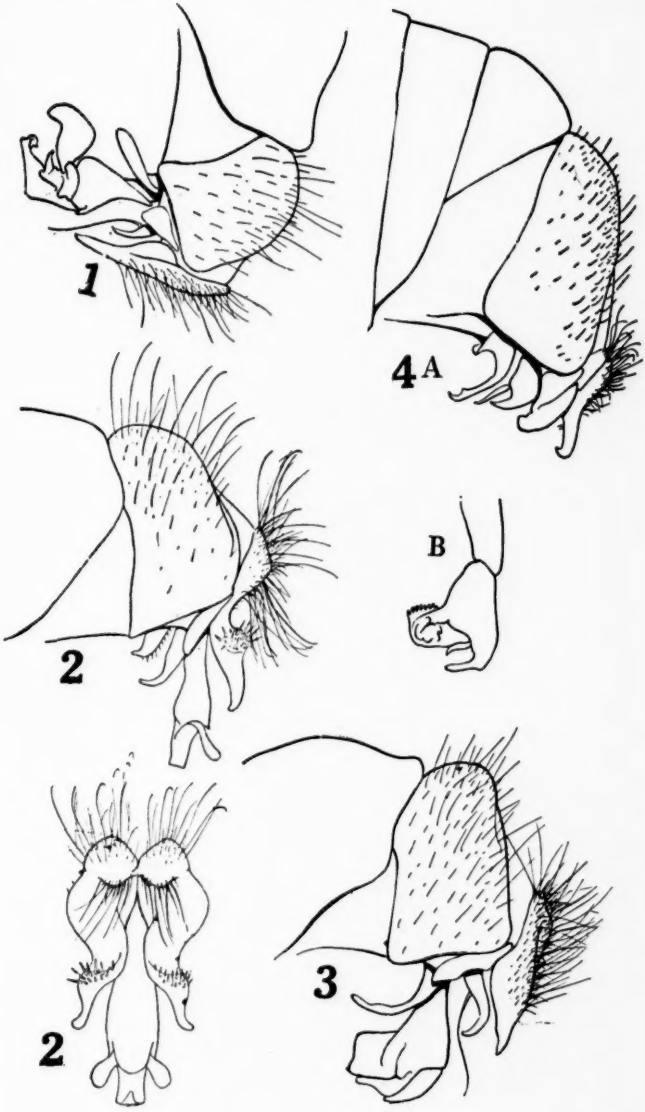
Fig. 1.—*Sarcophaga camura,* n. sp., Left lateral view of male terminalia.

Fig. 2.—*Sarcophaga rimosa,* n. sp., Left lateral view of male terminalia, and rear view of male penis and forceps.

Fig. 3.—*Abacantha zygox,* n. sp., Left lateral view of male terminalia.

Fig. 4.—*Tripanurga albicans* (Wied.). A.—Left lateral view of male terminalia, B.—Penis from same view.

PLATE VIII



ANTILLEAN ASCALAPHIDAE

By NATHAN BANKS
Museum of Comparative Zoology, Cambridge, Moss.

Recently Dr. G. N. Wolcott of Puerto Rico sent me a pair of a small Ascalaphid taken in the southwestern part of the island. This has included me to go over the material in the Museum collection, to straighten out certain points in Van der Weele's Revision and in Prof. R. C. Smith's paper on the Haitian species. We have here the types of Burmeister's *senex* and of Hagen's *avunculus*.

Burmeister had two specimens, one from Cuba, one from Savannah, Georgia; these are the same species, and I find no differences between Cuban and United States material but with greater differences between various specimens in the United States. Thus Van der Weele's subspecies, *hageni*, becomes a synonym of *senex*.

Van der Weele, having seen a specimen in the Berlin Museum labeled "*avunculus*", surmised that it might be a Hagen type, and said the antennae were no longer than usual in *senex*, and that Hagen had made a mistake, and put *avunculus* as a synonym of *senex*. The two types of *avunculus* are here, both males, and with the antennae over thirty millimeters long, so distinct from *senex*. Prof. Smith listed from Haiti several species, which to me are only specimens of *sancti-domingi* in varying conditions. But one of them is so different I shall describe it as new.

Of the species *macleayana*, that Guilding described from St. Vincent, I have seen no specimens, and the photograph shows little, if anything, to separate it from *sancti-luciae* Weele.

The species in the collection can be tabulated as follows:

1. Hair on lower face dark; stigma never dark; large species 2
   Hair on lower face white or almost so 3
2. In hind wing behind the bend of the first anal the wing is so swollen that the network of cross veins extends past the bend toward the base of wing; four cross veins before radial sector in fore wing ... *villosus (ampla)*
   In hind wing the network is interrupted behind the bend of the first anal, the wing being more narrow; three cross-veins before radial sector in fore wings ..... *walkeri*
3. Antennae of male over 30 millimeters long, much longer than wings; femora as well as tibia very pale ..... *avunculus*
   Antennae of male not 30 millimeters long 4
4. Stigma in both wings plainly dark (except in teneral specimens); femora rather evenly dark; hair on front of mesonotum normally dark 7

Stigma in both wings very pale or yellow; small species 5
5. Mid and hind femora pale, but with dark apical band; white hair on front of mesonotum; much white hair in tuft at base of antennae; stigma yellow ..... *smithi*
Hair on mesonotum plainly dark, mid and hind femora more evenly dark .. 6
6. Male with a dark spot by stigma of fore wing, female with spot in hind wing ..... *opposita*
Male without dark spot in fore wing; vertex a little more narrow ..... *banksi*
7. In fore wings the tip slightly more acute; stigma usually covering four veinlets, longer than high 8
In fore wings the tip rounded; stigma shorter, usually higrer than long ..... *sancti-domingi*
8. From Cuba and Bahamas; venation of apical part of wing denser, between the third and fourth branches of the radial sector nine to twelve or or more cells ..... *senex*
From St. Lucia; venation less dense, between the third and fourth branches of the radial sector eight or less cells ..... *sancti-lucia*

Ululodes villosus Pal. de Beauv.

The *U. ampla* McLach is considered a synonym of this by Van der Weele, and doubtless correctly, as there is probably not another species so large from San Domingo. The Museum has ten specimens from Samana Bay. Its large size and tinted wings readily separate it from all other except *U. walkeri.*

Ululodes walkeri Weele

Separated from *U. villosus* by the narrower wings, especially the hind pair, and darker hair on head. In the collection is one specimen from Poey, wholly pale-winged, and a very dark-winged specimen from the coast below Pico Turquino, 26 to 30 June (Darlington). The tips of hind wings are almost black. It was described from Jamaica.

Ululodes senex Burm.

The two types (both females) are here; I can see no difference between them that is not found in greater degree in U. S. and Cuban specimens. It is common in Central and Western Cuba. Both male and female sometimes have a dark spot near stigma in hind wing; in some specimens the whole wing is suffused with yellowish brown. In two specimens (Hope, Arkansas and Dallas, Texas) there are four cross-veins before radial sector in the front wing of one side; in one (San Antonio, Texas) there are four in both front wings and tw o in each hind wing. The hair of the antennal tuft is white in front.

Ululodes avunculus Hag.

The two types (both males) are here; the antennae are over 30 mm. long, much longer than wings; both are from Poey, no definite locality; there is also another Poey male, collected later, and in 1936 Darlington took a male on the south side of Pico Turquino, Oriente, Cuba, 11 June, at 3 to 5,000 feet. I am not sure of the female; there is a female bearing the same number as Poey's third specimen; it is very similar to *senex*. The species is probably confined to Eastern Cuba.

Ululodes sancti-domingi Weele

This species is extremely close to *U. senex*, and shows the same color variations, sometimes a dark cloud in apex of hind wing, sometimes the whole wing tinted with yellowish brown. About the only character to distinguish it is the shorter stigma; the tip of wings is more rounded than in *senex*, but the difference is slight.

What Prof. R. C. Smith listed as *U. villosus* and as *U venezolensis* are this species; while the form called *U subvertens* is different and I described it as new—*U. smithi*.

Ululodes sancti-luciae Weele

Of this I have but one specimen from St. Lucia. It was described from one male from St. Lucia; had it been from Cuba I think it would be put with *U. senex;* the venation is less dense than in *senex* but not strikingly so.

Ululodes smithi sp. nov.

Face mostly dark; hair on lower part white, that at base of antennae largely white, but dark behind; hair on pronotum white, on front of mesonotum also white, above on mesonotum pale gray. Abdomen (♀) pale, with many black lines on sides, and above on several segments a median dark line, and on each side the elongate triangular mark as usual, with a small spot before it; apical segment largely pale, a median black stripe, and on each side a dark spot on the hind margin; legs pale, but mid and hind femora darkened toward tip, and the tibia within dark, tarsus mostly dark.

Wings hyaline, veins mostly dark, stigma in both wings plainly yellowish; in hind wings of female a dark spot behind stigma. Venation and shape of wing much as in *sancti-domingi*, apical field rather evenly three-celled; size of *sancti-domingi*.

From Port-au-Prince, Haiti, 23 Aug. (Smith). Type M.C.Z. No. 23192.

This was treated by Smith (Hayti Neuroptera) as *subvertens* Walk., a South American species with broader wings, hardly any

white in antenal tuft, etc. A male from the same locality has the antennal tuft darker and darker hair on mesonotum, and may belong to this species.

Ululodes opposita sp. nov.

Face mostly dark, hair on lower part white, the tuft at base on antennae with a little white in front, but mostly dark; antennae pale, with dark apical ring on each joint, tip brown; hair on the pronotum white, that on mesonotum dark gray to brown; pleura with long white hair. Legs pale, the hind femora rather evenly brown; abdomen of male dull black, above with a velvety stripe, broader in front, on each side of segments two, three, and four, between these marks is a median pollinose stripe; hair black, except toward base beneath where it is white; abdomen of female mostly black, above on second, third, and fourth segments mostly pale, with black lines, last segments above mostly black, with a pale median line on apical half.

Wings hyaline; veins mostly dark; stigma, in both wings, pale yellowish, over four veinlets, a little longer than high; tips of wings rounded; venation rather open, apical field with three or four rows of cells; in female a large black spot behind and beyond stigma in hind wings; in male with a more rounded black spot beyond stigma in the fore wings.

Length of fore wing, male, 22 mm., width 6 mm.

Length of fore wing, female, 23 mm., width 6.8 mm.

Length of antenna, male 21 mm., of female 22 mm.

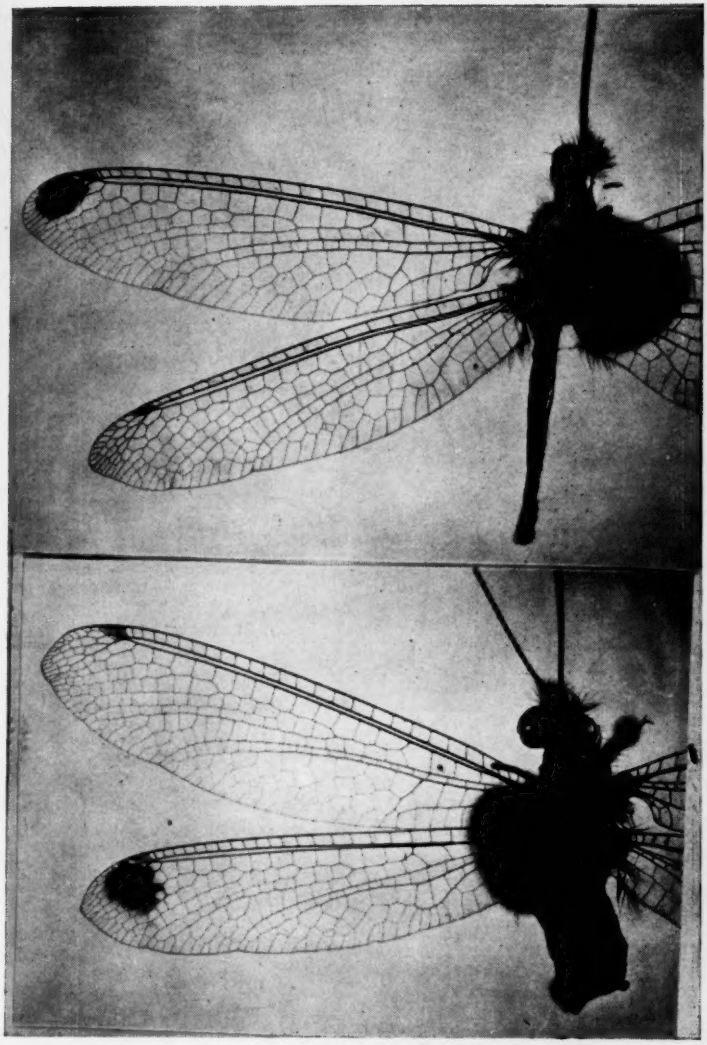
From Cabo Rojo, Puerto Rico, near lighthouse, 4 November. G. N. Wolcott and L. P. Martorell. Type M.C.Z. No. 23193.

Unique in the genus in having a black spot in the fore wings.

Ululodes banksi Weele

Of this Jamaican species we have but one specimen; Kingston, 29 Aug. (Darlington). It is very similar to *U. opposita*, except that the male has no black spot in apex of fore wing. It is a little smaller, and the wings more narrow.

PLATE IX



EUXESTA STIGMATIAS LOEW, AN OTITID FLY INFESTING EAR CORN IN PUERTO RICO

By BERNARD A. APP, Bureau of Entomology and Plant Quarentine, U. S. Department of Agriculture.

This paper reports the results of observations made on the otitid fly *Euxesta stigmatias* Loew in connection with investigations on insects attacking corn in Puerto Rico under special funds provided to the Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture. The studies were conducted in cooperation with the Experiment Station of the U. S. Department of Agricutulre at Mayagüez, P. R., where laboratory and other facilities were provided for the work. The Isabela Substation of the Agricultural Experiment Station of the University of Puerto Rico, Río Piedras, also cooperated in supplying plots for some of the experiments. Acknowledgement is also made of the advice and assistance rendered by various members of the Station staff. The observations were made from August 1935 to June 1936.

When these studies were begun, corn ears were found infested with dipterous maggots, which caused a very unsightly and malodorous condition, spoiling many ears for market as roasting ears. It was at first thought that the high humidity and heat prevailing in Puerto Rico had caused the silks to rot and that the maggots were feeding on this decaying material. The large number of ears to infested, however, seamed to indicate that these maggots were inflicting primary injury to corn. Further examination disclosed many whitish, elongate eggs deposited on fresh silks near the juncture with the husks. Some of these eggs, together with maggots from infested ears, were taken to the laboratory and reared to maturity on fresh corn silks, and were thus found to repesent the same species. Samples of both lots were sent to Washington, where they were determined as the otitid fly *Euxesta stigmatias* Loew (fig. 1).

DISTRIBUTION

This fly seems to be generally distributed throughout the tropical part of the Western Hemisphere. Records of the U. S. National Museum show it to be reported from the following locations:

West Indies: Puerto Rico, Cuba, Dominican Republic, Nassau, Virgin Islands.

British West Indies: Barbados, Dominica, St. Vincent, Jamaica.

Central America: Canal Zone, Panama.

South America: Brazil, Bolivia, Paraguay, Perú.

North America: Mexico, Florida.

According to these records the fly has been taken on sugarcane, guava, corn, *Eugenia* spp., orange, and the stem of banana.

Abundance

No field of corn in the ear stage was examined in which this maggot was not present, and usually infesting a large majority of the ears. The percentage of infested ears seems dependent on the stage of maturity of the corn. The ears usually become infested when they are one to two weeks past silking, but as the corn matures the maggots leave the ears to pupate. Table I gives the percentage of infested ears in some fields examined throughout the period of observation. Field counts were made nearly every month and showed the fly to be present at all seasons.

Table 1—PERCENTAGE OF CORN EARS INFESTED WITH MAGGOTS OF *EUXESTA STIGMATIAS* IN DIFFERENT FIELDS EXAMINED IN PUERTO RICO

Date of Examination	Locality	Infested Ears Percent
1935		
September 3	Isabela	67.0
October 14	Isabela	31.0
November 6	Isabela	28.0
December 16	Las Mesas (Mayagüez)	30.0
1936		
January 8	Lajas	68.0
February 3	Mayagüez	92.9
May 11	Isabela	97.0
June 1	Mayagüez	96.0
June 5	Isabela	92.0

Damage

There is little exterior evidence of the infestation, as the silks usually dry in the normal manner. Examination of an infested ear reveals that inside the husks, from the tip where the eggs hatched, the silks are rotted down to the grain. The kernels on the tip of the ear are only hollow shells, the maggot having consumed their entire contents. The maggots work between the rows of grain near the cob, they enter the kernal at the bottom, consuming its contents and leaving a hollow shell, and then attack the next kernel. In most

cases only a few kernels at the tip are destroyed, but many ears were infested with maggots in their entire length. Frequently maggots were working in the pith of the ear, which resulted in a stunted, soft ear bearing grain of little value, when any was produced. In field corn most of the maggots had pupated by the time it was ready to harvest. A mold seems to follow the feeding of these maggots, making it impossible to leave seed ears in the field until fully mature. Perhaps the greatest damage caused by this insect is the reduction of the market value of roasting ears by the unsightly and malodorous condition imparted to them.

Life History and Description of Stages

Eggs.—The minute, elongate, whitish eggs (fig. 2) are laid just below the tips of the husks, and usually in strings fastened end to end. During oviposition the female stands on the ear and curves her ovipositor down below the tip of the husk. Some eggs are laid as soon as the silks appear, and as the silks grow out the eggs are pushed out with them and remain attached to them. More often, however, the eggs are laid after the silks have grown out, and they remain just below the tip of the husk until they hatch. Of 200 plants examined during December 1935, 191 were observed to produce silk, and of this number 189, or 98.9 percent, were infested with eggs of this otitid. On this group of plants the silks became infested with eggs on an average of 1.12 days after they appeared. The number of eggs laid on one ear ranged from a few dozen to several hundred. Some of the eggs are lost as the silks grow out, but six ears brought into the laboratory were found to contain 558, 685, 47, 146, 431, and 248 eggs, respectively, or an average of 352.5 eggs per ear. The length of the egg stage is from two to four days. In the fall of 1935 a sample of eggs began hatching on the second day after deposition and completed hatching by the fourth day. On June 18, 1936, some eggs laid the previous day were brought into the laboratory, where they began hatching on June 21 and completed hatching by June 22.

Larvae.—The larvae are also minute and white in color, with darker spiracles and mouth parts. They begin feeding on the fresh silks and work down to the developing grain. When full grown (fig. 3), they are about three-eighths of an inch long. One ear may contain a few to several hundred maggots. Five ears brought into the laboratory were found to contain 545, 113, 108, 106, and 199

larvae, respectively, or an average of 214.2 per ear. Of 200 plants examined daily in the fall of 1935, 191 were observed to silk and 188, or 98.0 percent, because infested. The average length of the larval stage, based on to samples, was 7.46 days (table 2).

The Pupae.—The pupal stage of the fly is passed in a small, brown puparium about one-eighth of an inch in length (fig. 4). In the early stages it is light brown in color, but a it grows older it changes to a dark brown. Before pupation the maggots leave their feeding places and migrate to drier locations. In the laboratory they readily pupated in moist sand, into which they burrowed to the depth of about one-fourth of an inch. Some puparia were found on the tips of the ears among the dry silks, but as only a few were found it is probable that most of the maggots pupate in the soil. The average length of the pupal stage was 7.38 days, on the basis of ten samples reared to maturity.

TABLE 2—DURATION OF LARVAL AND PUPAL STAGES OF *EUXESTA STIMATIAS*, MAYAGÜEZ, P. R., 1935-36

Sample	Larval stage		Pupal stage	
	Individuals	Mean duration	Individuals	Mean duration
	Number	Days	Number	Days
1	19	7.42	19	7.74
2	7	7.00	7	7.14
3	8	7.50	7	7.64
4	12	6.58	12	8.09
5	13	7.31	11	7.14
6	13	7.46	10	7.74
7	17	9.06	12	6.52
8	15	7.07	13	7.70
9	18	7.33	11	7.12
10	8	7.88	5	6.92
Total or average	130	7.46	107	7.38

Adults.—The adult is a small fly of a dark metallic green color with reddish eyes and wings banded with black (fig. 1). The wings are constantly in motion even when the insect is otherwise at rest. The adults are very abundant in cornfields, where they seem to cluster about the parts of the plant that are likely to be moist, such as the tassel and the silks. They were observed ovipositing on the larvas of young coun, but no larvae seemed to come from these eggs. As many as five females have been observed ovipositing on the same ear at the same time.

Control

No attempt was made to control the larvae of this insect in the investigations carried on in Puerto Rico in 1935 and 1936. The protected location of the eggs and the habits of the young maggots in entering the ears after hatching would make control rather difficult. However, some of the experimental control measures used against the corn ear worm (*Heliothis obsoleta* F.) were found to reduce the number of ears infested with *Euxesta* maggots. The results are shown in table 3.

Because most of the eggs are laid below the tips of the husks and the maggots feed inside the husks, poisoning with insecticides was difficult. All the insecticides tested, however, reduced the infestation in some degree, and they all gave better results in the tests completed in June than in those completed in February. This is, no doubt, due to the fact that the fall applications of dust to the silks were delayed until approximately 50 percent of plants had silk, whereas the spring applications were begun soon after the first silk was observed and continued until silks were dry.

Several hand methods of control also reduced the number of infested ears. Cutting the silks and squeezing the tips of the ears had little effect on the larvae. When the silks were cut the field deposited numerous eggs on the cut tips. Those methods that covered the ear or constricted the husk gave better results than other methods. A paper tip consisted of a piece of brown wrapping paper rolled around the tip of the ear and tied securely with string. These tips were applied soon after the plants silked. The wires, hog rings, and strings were also applied as soon as possible without interfering with pollination. The effect of wires and hog rings was about the same as that of the paper tips, but the strings gave poorer results.

TABLE 2—EFFECT ON *EUXESTA STIGMATIAS* OF VARIOUS METHODS USED TO CONTROL THE CORN EAR WORM

Method	Test at Mayagüez Completed February 3, 1936			Tests at Mayagüez Completed June 1, 1936			Tests at Isabela Completed June 5, 1936		
	Number of ears	Percent infested	Percent control	Number of ears	Percent infested	Percent control	Number of ears	Percent infested	Percent control
Hog rings	224	63.92	28.93	342	55.32	40.67	523	46.96	45.07
Paper tips	127	67.99	24.86	304	55.19	40.80	518	46.88	45.15
Wires	172	62.47	30.38	.....	.....	.....	490	51.24	40.79
Strings	163	75.62	17.23	.....	.....	.....	518	61.29	30.74
Cut silks	201	90.95	1.90	338	75.33	20.66	528	82.81	9.22
Squeezing tips	198	90.47	2.38	336	86.29	9.70	514	83.53	8.50
Barium fluosilicate and talc (1:1)	161	82.16	10.69	361	66.17	29.82	542	64.73	27.30
Magnesium arsenate and talc (8:2)	193	79.52	13.33	339	78.63	17.36	546	68.51	23.52
Derris and talc*	186	89.21	3.64	357	83.64	12.35	533	70.86	21.17
Lead arsenate and talc (8:2)	209	75.22	17.63	354	71.65	24.34	538	69.06	22.97
Check	223	92.85	.....	321	95.99	.....	552	92.03	.....

* In the tests completed February 3 a derris and talc mixture of 0.75 percent rotenone content was used; in the later teste the rotenone contest was 1 percent.

SUMMARY

The otitid fly *Euxesta stigmatias* Loew is a serious pest of corn, especially roasting ears for market purposes, in Puerto Rico. The maggots have been observed in all sections of the island and at all seasons of the year. The pest at present seems to be restricted to a tropical habitat, so far as collection records of this insect are known. In most fields examined a large percentage of the ears were infested, and many entire ears were destroyed. Under laboratory conditions the fly was reared from egg to adult in as few as 18 days; so there are many generations during a year.

Although no special studies were made on control, in some experiments in control of the corn ear worm there was a reduction in the number of ears infested with maggots of *Euxesta stigmatias,* which suggests that some of these measures may also be useful in controlling this pest.

Explanation of Plates

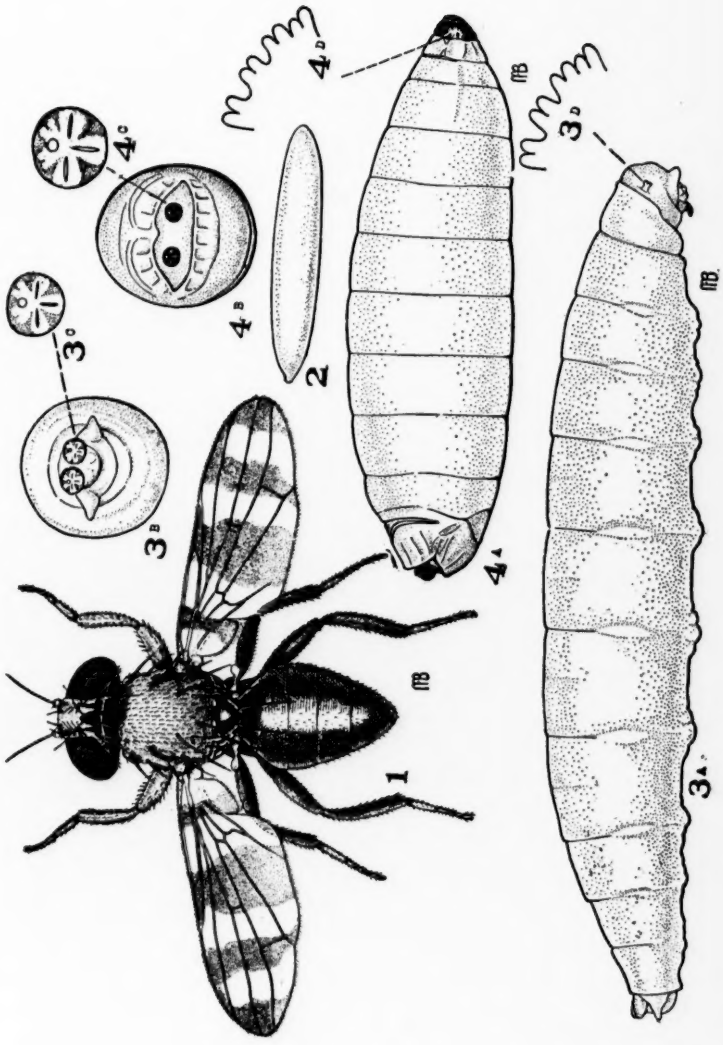
Fig. 1.—Adult of *Euxesta stigmatias* Loew, the larvae of which cause damage to roasting ears in Puerto Rico.

Fig. 2.—Egg of *Euxesta stigmatias.*

Fig. 3A.—Larva of *Euxesta stigmatias,* lateral view. B—Posterior view. C—Posterior spiracle. D—Anterior spiracle.

Fig. 4A.—Puparium of *Euxesta stigmatias,* lateral view. B—Posterior view. C—Posterior spiracle. D—Anterior spiracle.

PLATE X



DESCRIPTION AND BIOLOGIC NOTES ON A *TIPHIA* (HYMENOPTERA: SCOLIIDAE) FROM HAITI

By GEORGE N. WOLCOTT, *Entomologist*,
Agricultural Experiment Station, Río Piedras, P. R.

The normal scarcity of white grubs in cultivated fields in Haiti seemed most remarkable to one accustomed to their former great abundance in Puerto Rico. To be sure, the introduction of the giant Surinam toad, *Bufo marinus* L., into Puerto Rico from Barbados and Jamaica, and its rapid increase in numbers, largely feeding on May beetles (which are the adults of white grubs), has recently so greatly reduced the numbers of white grubs to be found in the cane fields of Puerto Rican lowlands (**3**) that conditions in the two countries now appear substantially similar. But until a few months ago, no introduced Surinam toad was present in Haiti, and the native toad of Haiti, *Bufo gutturosus* Latreille, was no more noticeably abundant than the comparable native toad of Puerto Rico, *Bufo lemur* Cope. The little burrowing owl, *Speyotyto cunicularia troglodytes* Wetmore & Swales, quite abundant in Hispaniola, but not present in Puerto Rico, may be a considerable factor in reducing the number of May beetles, altho the only stomach contents record gives no indication that the owl eats this particular kind of beetle (**2**). Indeed, the most obvious factor in white grub control in Haiti is the abundance of the parasitic wasps belonging to the genus *Tiphia*.

In all the years that numerous entomologists have been collecting insects since the time of Stahl and Gundlach, only four specimens of *Tiphia*, all of which now repose in the U. S. National Museum, have been collected in Puerto Rico. In Haiti, on the contrary, several individual collections of adults of both sexes were made by the writer from time to time at various localities in the lowlands, and the number to be seen at Kenscoff the first time it was visited was so large that the actual number of specimens collected can hardly give a correct impression of the abundance of *Tiphia*. Subsequent visits only served to confirm this preliminary observation of its abundance in the mountains of Haiti. While the wasps occur on various plants, and feeding at various flowers, they greatly prefer those of the wild parsnip, *Pastinaca sativa* L., or the minute droplets of honey dew to be found on sooty mold blackened leaves of guava

bushes infested with the green scale, *Coccus viridis* Green. They are to be noted feeding only in the bright sunshine, and appear to be more abundant and larger in size at the higher altitudes, specifically at Kenscoff (elevation 1,450 meters) up to the pass on the old trail to Furcy. The records of former collections, copied from specimens and the accession cards of the Division of Entomology at Damien, are as follows:

FEMALES

Haiti Acc. No.	Locality	Date	Host	Collector	Number of Specimens
58-27	Mt. Puilsboreau	May 28, 1927	Wild carrot	GNW	1
	Post Chaubert, Le Trou	Nov. 10, 1927		GNW	1
	Kenscoff	Nov. 23, 1927	*Pastinaca*	GNW	2
	Kenscoff	Jan. 5, 1928	*Pastinaca*	GNW	1
	Kenscoff	May 10, 1927	Cabbage	E. Ducasse	1
174-28	Kenscoff	March 14, 1928		E. Ducasse	2
	Mirebalais	Aug. 9, 1928		R. C. Smith	2
118-33	Morne La Selle	Sept. 1933		A. Audant	1
74-34	Morne La Selle	June, 1934		A. Audant	1

MALES

	Mt. Puilsboreau	Nov. 9, 1927	Guava	GNW	1
	Le Trou	Nov. 10, 1927	Guava	GNW	1
59-27	Kenscoff	April, 1927	*Pastinaca*	GNW	1
	Kenscoff	Nov. 23, 1927	*Pastinaca*	GNW	17
5-28	Port-au-Prince	Jan. 12, 1928		GNW	1
171-28	Kenscoff	March 14, 1928	*Clerodendron*	E. Ducasse	4
	Kenscoff	April 4 & 26, 1927	Beans	E. Ducasse	11
59-28	Port-au-Prince	May, 1928		A. Audant	2
	Mirebalais	August 9, 1928		R. C. Smith	1
	Hinche	August 30, 1930		H. L. Dozier	1
	Kenscoff	August 24, 1930		H. L. Dozier	4
104-33	Morne La Selle	Sept., 1933		A. Audant	2
74-34	Morne La Selle	June, 1934		A. Audant	1

A study of the specimens remaining in the collection at Damien, together with fresh material collected at Kenscoff in December 1937, indicates that all represent but a single species, for which the name *hispaniolae* is proposed. This species may be characterized as follows:

Tiphia hispaniolae sp. nov.

Female.—Entirely black, polished, length 15 mm.; head, basal segment of antenna, anterior dorsal pronotum, scutum, legs and posterior margins of abdominal segments with long silvery hairs. Head, coarsely but unevenly punctate, as is also anterior pronotum, with a line of deep punctures almost coalescing to form a deep transverse groove with posteriorly pointing hairs, posterior and lateral pronotum polished and impunctate. Notauli of scutum ending in deep punctures before base, no antero-medial groove, scutum coarsely but sparingly punctate. Preapical groove on posterior aspect of mesepisternum. Prepodeal areola almost twice as long as broad, anterior lateral margins slightly curved outwards, posteriorly straight and parallel, median carina not reaching apex. Median carina of posterior aspect extending nearly to apex. Wings translucent black, lighter in marginal and radial cells, with transparent lines

paralleling the opaque black veins to outer margin. Second intercubital vein somewhat sinuous, joining the radius in a broadly rounded angle. Cubital mark present in large individuals, only at marginal vein in smaller specimens. Hind basitarus not grooved, major calcarium of hind tibia only slightly wider towards middle than at base. First tergite of abdomen with very deep preapical groove, all tergites anteriorly lightly punctured, postmedially almost impunctate, a transverse row of punctures near apex. Pygidium deeply impuctate only on basal half.

Described from 33 specimens, Haiti & Puerto Rico Acc. No. 133–37, collected between Kenscoff and Furcy, Haiti, elevation about 1,700 meters, December 5, 1937 by George N. Wolcott.

Male.—Black, polished, length 9 mm., punctures and pubescence much finer than in female, in this respect quite unlike *Tiphia argentipes* of Cuba, which Cresson (1) describes as "more slender and hairy (than the female); the punctures of the mesothorax and abdomen deeper and closer." Radial cell greatly exceeding second cubital, basal half and apical margin of forewing hyaline, elsewhere fuscous, basal third only not pubsecent, veins black. No denticle on fifth sternite of abdomen. First tergite with deep preapical groove and carina, also a prominent median transverse carina. Cresson mentions no such median carina, in his description of *argentipes;* Miss Sandhouse states that it does not occur in the Puerto Rican males; it does not appear on a single male collected at Santiago, República Dominicana, by S. del Rosario on March 26, 1936, and now in the collection of the College of Agriculture at Mayagüez, P. R., loaned to me for study by Dr. Stuart T. Danforth; therefore this character appears to be distinctive for the males of this species, separating it from others of the Greater Antilles.

Described from a single specimen (TYPE) out of 5 examples, Haiti & Puerto Rico Acc. No. 136–37, collected at Kenscoff, Haiti, December 13, 1937 by George N. Wolcott, compared with 12 examples, Haiti Acc. No. 59–27, collected at Kenscoff, November 23, 1927 by George N. Wolcott. Type and accompanying females for the U. S. National Museum, others for the British Museum, the bulk of the material in the collection at the Agricultural Experiment Station at Río Piedras, P. R. and at Damien, Haiti.

The May beetles of Haiti vary tremenduously in size (**4**); and no information is available as to which of these several species of white grub is attacked by *Tiphia hispaniolae.* It is possible, however, that despite the selectivity displayed by continental species of *Tiphia,* different instars of approximately the same size of most or all of the grubs of Haiti are attacked by the females of the single species of *Tiphia* found there. If the Haitian *Tiphia* is in fact so unselective in its attack on white grubs, presumably it would attack other species of white grubs in an environment similar to that of Haiti. This would make it a most valuable addition to the fauna

of Puerto Rico, more especially at the higher altitudes where it thrives, but where *Bufo marinus* does not and is thus of so little value in white grub control.

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3. **Wolcott, G. N.**, "The White Grub Problem in Puerto Rico." Fifth Congress, International Soc. Sugar Cane Technologists, pp. 445–456, fig. 5, ref. 11. Brisbane, Queensland, 1936.

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THE INTRODUCTION INTO PUERTO RICO OF *LARRA AMERICANA* SAUSSURE, A SPECIFIC PARASITE OF THE "CHANGA", OR PUERTO RICAN MOLE-CRICKET, *SCAPTERISCUS VICINUS* SCUDDER

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For many years young tobacco plants in Puerto Rico have suffered from the attack of an insect called by the growers the "changa". Its scientific name is *Scapteriscus vicinus* Scudder, and, altho it is not a native insect, but, merely due to the fact that it appears to be more abundant and to cause more damage in Puerto Rico, it has ordinarily been known elsewhere as the Puerto Rican mole-cricket. (fig. 1.)

The changa occurs mostly in light sandy soils, thru which it can readily burrow with its powerful shovel-shaped front legs. During dry weather it remains at considerable depths in the soil, but during wet weather it comes up, making mole-like burrows just below the surface, feeding on the tender centers of the stalks of whatever young plants may happen to be there. It does not confine its attack to tobacco; it merely happens that the best tobacco soils are also the light sandy soils best adapted to the changa. When such soils are planted to sugar-cane, the changa attacks the young cane shoot quite as readily, and the presence of the changa makes vegetable growing practically impossible in many localities where otherwise it might be a profitable practise.

The changa can be, and is, artificially controlled. Many years ago tobacco growers learned that by wrapping each young transplanted tobacco plant in a broad, tough leaf of the mamey tree, *Mammea americana* L., it would be protected against attack by the mole-cricket until it had grown sufficiently large and tough to be no longer subject to injury. Cane-growers learned that, instead of placing the cane "seed" piece horizontally in the ground and lightly burying it, if stuck in at an angle, roots would start from the lower end deep in the soil, and the upper eyes would send out shoots above the surface of the soil, out of reach of the attack of the changa. Some vegetables can be protected by the method used for young tobacco plants; others can not be grown in "changa" soils, and their cultivation is no longer attempted there. It should be es-

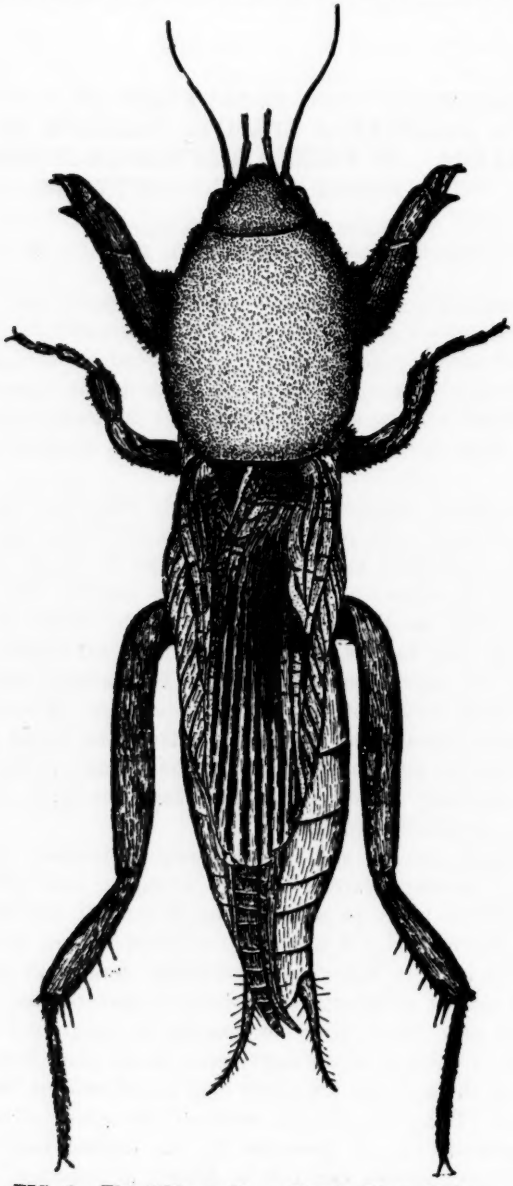

FIG. 1. The "Changa", or Puerto Rican Mole-Cricket, *Scapteriscus vicinus* Scudder, dorsal aspect. Six times natural size. (Drawn by F. Seín.)

pecially noted, however, that these methods of preventing changa injury do not kill the pest, or even tend to reduce its numbers; they merely protect individual plants from attack at that time, and must be repeated for each succeeding crop. Indeed, while reasonably well adapted to small scale cultivation in some tobacco regions, they quickly tend to exhaust all possible supplies of fresh mamey leaves for rapidly expanding, large scale plantation production.

A positive method for destroying the changa (**2** and **6**), consists in the application around each tobacco plant, as set out in the field, of a ring of wheat flour and Paris green, the mixture containing twenty to fifty times as much bait as poison. This poison bait is also applicable for other crops, when distributed as lumps in the prepared field before the crop is planted. The wheat flour proves to be more attractive to the insect than any green vegetation, and is promptly eaten in such quantities that the admixed poison causes death. Because of its effiectiveness in ensuring an even stand of tobacco, and despite the very considerable expense involved, this method is in extensive use in Puerto Rico at the present time. No other method suggested even approaches it in value. Manufacturers of aluminum foil suggested that their product might prove more desirable than mamey leaves, but the changa promptly burrows thru any thickness of foil which can be readily wrapped around the roots of a seedling, and also, the foil does not rot and naturally disappear, as do the mamey leaves, when the tougher and older tobacco plant no longer needs protection. Nor do suggested improvements in the Paris green-flour mixture appear to be applicable in Puerto Rico, where the original formula is still universally used. Indeed, the sole objections to its use are on the basis of cost and trouble of application.

Naturally, the control of the changa by natural means has repeatedly been suggested, but the birds which are large enough to be effective (**10**), are scarce or non-existent in the thickly settled regions where tobacco is grown. The large ground lizard, *Ameiva exsul* Cope, which also feeds on the changa (**14**), is almost equally scarce where its presence would be of economic value. Much was expected of the giant Surinam toad, for the changa is more or less comparable in size, terrestrial habits and clumsiness to the May beetle, yet at the time when the toad was most abundant and was most effective in rapidly reducing the numbers of the May beetle, the changa formed but an insignificant fraction (only 2.4 per cent) of its food (**7**), and the proportion has not since been increased (**15**).

The scarcity, or comparative inefficiency in the control of the changa, of all of these larger predators does not by any means eliminate all possibilities of natural control. The search abroad for a specific insect parasitic only on Puerto Rican white grubs was fundamentally hopeless because the local species are endemic and present nowhere else. But the Puerto Rican mole-cricket is unquestionably an introducted insect, as many of the older tobacco growers could remember a time when it was not present to trouble them. Tradition indicates its appearance after the distribution of a shipment of Peruvian guano followed by the destruction by hurricane of most of the large birds which might have consumed these first few introduced individuals. It is not mentioned by Ledru (**8**), and Busck (**3**) notes that Dr. Augustin Stahl, the first Puerto Rican naturalist, told him that "it was a comparatively new insect in Porto Rico, having been introduced within his recollection." Its subsequent abundance in Puerto Rico unquestionably indicates that it has here escaped from its effective natural enemies, and that a search for them abroad might furnish the key to its control in Puerto Rico.

The establishment of the Board of Commissioners of Agriculture in 1911 made possible the first attempt at such a search. Mr. Patrico Cardín, recently graduated from Massachussets Agricultural College and promptly appointed Entomologist at the Experiment Station at Santiago de las Vegas, Cuba, had indeed reported such a specific parasite (**4**), and the writer, at that time employed by the Board in the collection and shipment of parasites of white grubs, was sent to Cuba to investigate. The sole basis for Cardín's statement was a single cocoon which he had picked up in a field being plowed, from which the *Tiphia* wasp had emerged, but in the silken network of threads on the outside of which was still entangled what he supposed to be the skeletal remains of a changa. A more critical examination indicated that what he supposed to be the burrowing forelegs of a changa were in fact the jaws of a white grub.

To more securely establish the actual occurrence of the mole-cricket in Cuba, previously recorded by Cook (**5**) as being present at Santiago de las Vegas, but of which no specimens remained in the collection, Cardín organized an expedition from the tobacco center of San Juan y Martínez on one of the holidays when he was free to be absent from his office in the Experiment Station. The imposing cavalcade, starting long before daybreak, sent out several messengers explaining the object of our search, but it was not until nearly noon, as we were feasting on roast pork and other native

dishes in the shade of a clump of royal palms grouped around a spring, that we were interrupted by an excited and shouting rider bearing a single but unquestionable mole-cricket. Somewhat crestfallen at the reward of a $5 bill, he was only partially satisfied when assured that this was the equivalent of the solid silver dollars which he had anticipated. What became of this dearly obtained specimen is uncertain, for it has not recently been found in the collections in Cuba, Puerto Rico or at Washington. The difficulty of obtaining it, however, coupled with the youthfulness and inexperience of the writer, precluded the further prosecution of a search for its possible parasite at that time.

The erroneousness of Cardín's original observation should not obscure the fact that true parasites of mole-crickets do occur in various parts of the world. Possibly the best known is *Larra luzonensis* Rohwer, which was discovered in 1917 in the Philippine Islands by Mr. F. X. Williams of the Hawaiian Sugar Producers' Association Experiment Station when he was searching for a parasite of *Gryllotalpa africana* P. B. (**11**). This mole-cricket, accidentally introduced into Hawaii, was a serious pest of sugar-cane there until Mr. C. E. Pemberton brought cocoons of the wasp from the Philippines to Hawaii, and reared and successfully established the parasite there (**12**). Each parasite of each species of mole-cricket is specific for that kind of mole-cricket only, thus at once indicating the uselessness of attempting the introduction into Puerto Rico for the control of the changa of the wasp which has been so effective in the control of the mole-cricket in Hawaii. Not only are they different species, the two mole-crickets are in different genera, and hopelessly unlike from the standpoint of their parasites.

The logical place to commence the search for a desired parasite is in a country with a similar climate, where the identical host is known to be present, but, presumably due to its parasite, not abundant. In every way, Cuba appeared to be the most desirable place for commencing a search for a parasite of *Scapteriscus vicinus* Scudder, the "changa" of Puerto Rico. As tentative plans were being made however, the Entomologist at present at the Experiment Station at Santiago de las Vegas, Mr. S. C. Bruner, sent word that a recent determination of all the mole-cricket specimens in the Station collection by Mr. J. A. G. Rehn, of the Philadelphia Academy of Natural Sciences, the recognized specialist in this group, showed them to be *Gryllotalpa hexadactyla* Perty (fig. 2), and that the Puerto Rican changa apparently did not occur in Cuba (**9**). There is no record of a

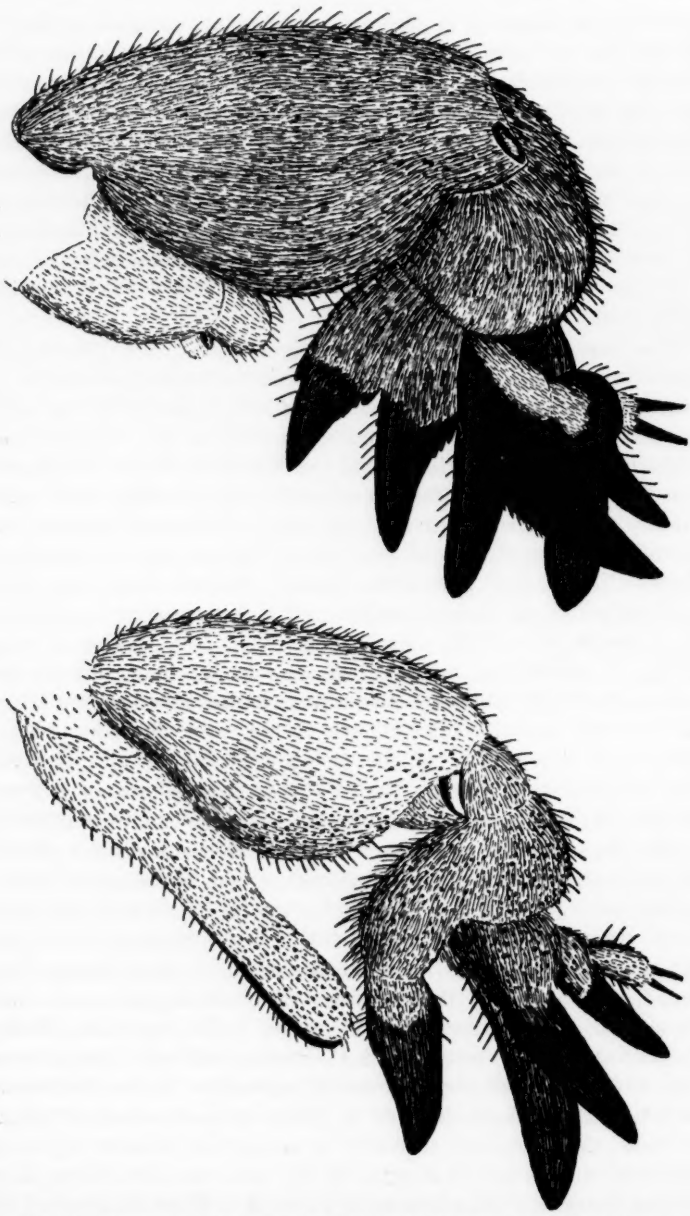

FIG. 2.—Foreleg of the West Indian Mole-Cricket, *Gryllotalpa hexadactyla* Perty (above), for comparison with that of the Puerto Rican "Changa", *Scapteriscus vicinus* Scudder (below). (Drawn by F. Sein.)

mole-cricket in Jamaica, and those from Hispaniola were open to doubt. Concerning the Lesser Antilles little definite information was available, but in Trinidad the writer had collected a number of specimens in 1912, which were still present in the collection at Río Piedras, and were unquestionably the same as the Puerto Rican species. At the time of their collection, various persons in Trinidad were questioned as to the status of the insect, but they knew it only from its injury to cricket fields, and not as a pest to agriculture.

Due to the close proximity of Trinidad to the continent of South America, it was to be supposed that any continental parasite of the mole-cricket would also be present there, and indeed, the presence of a parasite might be inferred from the supposed scarcity of the host. Furthermore, Trinidad is now so close to Puerto Rico by airplane that the problem of transporting the inferred parasite would be correspondingly simple.

The month of January 1936 was spent by the writer in Trinidad, where, thru the courtesy of Sir Geoffrey Evans, Principal of the Imperial College of Tropical Agriculture at St. Augustine, headquarters for the investigation were maintained at the College. No wasp which might be presumed to be a parasite of *Scapteriscus vicinus* was collected at this time in any part of the Island, all parts of which were explored, nor was any changa with indication of parasitism noted either at light or in fields being plowed. Indeed, the whole theory of the scarcity of the changa in Trinidad was found to be a misconception. Much of the Island is in virgin forest, or artificial forest of cacao, coffee and grapefruit trees. Furthermore, most of the area under cultivation to sugar-cane is heavy clay soil, entirely unsuited to the mole-cricket. But in the sandy open areas, such as the Savannah at Port-of-Spain, the campus and farm of the Imperial College, and Orange Grove Estate (in sugar-cane), the changa is in general more abundant than in Puerto Rico. And, judging by conditions observed about the lights on the campus, the Surinam toad is even less effective than in Puerto Rico in reducing its numbers.

By a most fortunate combination of circumstances, however, the time spent in Trinidad was productive in indicating where the parasite was to be found and how it might be collected. Mr. A. M. Adamson, formerly of Hawaii and at present Reader in Entomology at the College, possessed a copy of a paper by Mr. F. X. Williams (**13**) detailing his earliest searches for a parasite of the Hawaiian mole-cricket, in which an extended account, with beautiful illustra-

tions, was given of his finding *Larra americana* Saussure, a parasite of *Scapteriscus didactylus* (Latreille) = *vicinus* Scudder, in abundance at Belem, Pará, Brazil. Mr. Alan Pickles, Entomologist for the Department of Agriculture of Trinidad and Tobago, stationed at the College, had spent some weeks at Belem only a year or two before, and was of invaluable assistance in furnishing information about this part of Brazil, and more particularly, a letter of introduction to Dr. G. Hagemann, Zoölogist of the Museu Paraense Emilio Goeldi at Belem.

The official restrictions on the activities of foreign scientists (presumably directed primarily against pseudo-scientists and slippery crooks engaged in expeditions "Exploring for Profit") in Brazil at the present time are most strict, but due to Dr. Hagemann's efforts, an official permit to conduct investigations and to ship the parasites was promptly obtained. It should not be imagined, because of the reluctant and jittery attitude of official Brazil towards foreign scientists, that this in any way reflects the actual sentiments of individuals, or at least of those met by the writer during his stays in Belem. From the manager of the local airport of Pan American Airways, Mr. Alberto Soares, and his assistant, Mr. Mario Pereira da Rocha, and the manager of Hotel Grande, Mr. Julio Lima Lages, all three of whom were of invaluable assistance, to the casual passer-by intent on disposing of a snake around his neck, or a turtle on his head, or birds in cages, or numerous school-children volunteering to aid in catching "borbolêtas", everyone was uniformly most cordial and helpful.

Belem is now only a day's hop by airplane from Trinidad. Early on the first morning after arrival, on the outskirts of the city, along the railroad right-of-way reached by the carline marked "Souza", females of *Larra americana* were seen exploring changa tunnels in search of their host. A little later in the day, they began to frequent the flowers of *Borreria verticillata* Meyer (as determined by Mr. José I. Otero, of the Agricultural Experiment Station at Río Piedras), a plant which is common everywhere in Puerto Rico where the changa occurs. It is also so very abundant in Trinidad that the most extensive collections of the larger Hymenoptera were made from its flowers, but included no specimen of *Larra*. *Borreria* occurs mostly in fields being fallowed, in waste areas, in dry, unpastured meadows, and especially along railroad tracks, where, being least disturbed, it often grows in clumps as high as one's waist or shoulder.

In Belem indeed, it is only along the right-of-way of the railroad to Braganza that so many such large clusters are to be found that considerable numbers of Larrid wasps can be collected in a short time.

Mr. Williams had so meticulously recorded his observations in Belem that the wasps could be at once recognized: entirely black except for golden pubescence and bright chestnut red abdomen (fig 3). The field identification by the writer has since been confirmed by Miss Grace A. Sandhouse, from a large number of specimens sent to the U. S. National Museum, of which 85 were *Larra americana* (Sauss.), 1 *Larra altamazonica* Williams and 1 *Larra pacifica* Williams. He did not especially remark on how very quick and active they are when not on the ground, or how extremely wary and difficult to catch in the net when feeding at *Borreria* flowers, this being reserved for the writer to discover. He did note, however, that they died within a day or two in captivity, thus the problem of getting them alive to Puerto Rico appeared correspondingly difficult. A trial sending to Trinidad, however, showed that a few at least might survive the trip, and two weeks later the writer was en route back to Puerto Rico, accompanied by a Wardian cage of local manufacture, in the moist sand at the bottom of which had been thrust the cut ends of *Borreria* flower stalks, to provide nectar for the 78 wasps of *Larra americana* which it contained. Leaving Belem early in the morning at the time, one could at the earliest expect to be in San Juan by late the next afternoon. Mr. Francisco Seín, Assistant Entomologist, had managed, with the greatest difficulty, to collect 21 live changas to expose to the tender mercies of the expected parasites—actually only a fraction of a day's supply for the 25 wasps which survived the trip. It seemed much wiser to release the wasps immediately near Punta Las Marías, and hope that they could find a more abundant supply of food for their progeny than could be obtained by our activities. Released towards the beginning of a drought that lasted for three months longer, this was doubtless a vain hope, but at that time the vital importance in the wasp's economy of daily rains could hardly have been surmised. Even if this particular release did not result in the establishment of the parasite of the changa, the trip had at least shown where the parasite might be obtained in numbers, and, with the rapid transportation now possible by airplane, that some wasps would survive the trip for release in Puerto Rico. Apparently nothing more was lacking for a successful introduction than the opportunity to apply on a larger scale the information already obtained. Actually, to get so many wasps alive

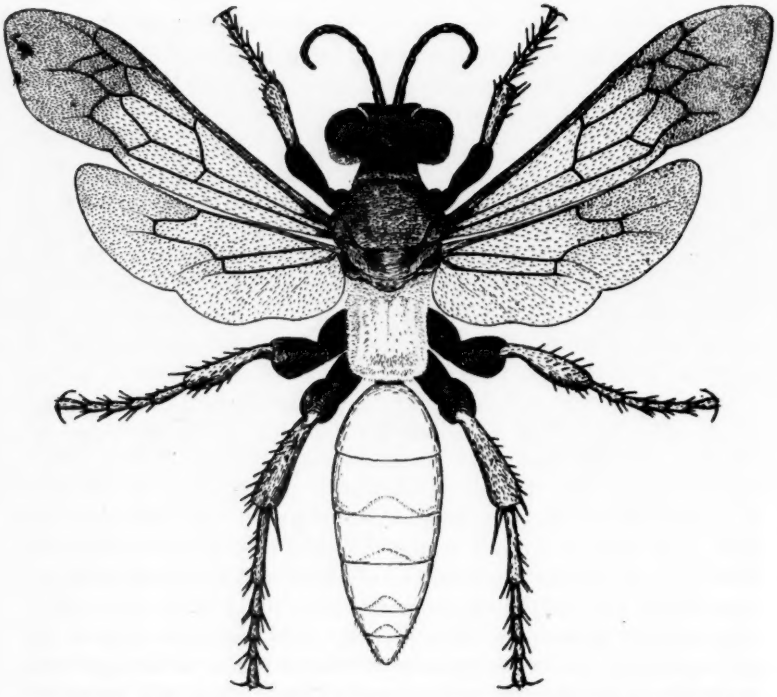

FIG. 3. Adult female wasp of *Larra americana* Saussure, five times natural size. (Drawn by F. Sein.)

to Puerto Rico at one time, and at the first attempt, was a most astounding bit of luck, altho in reality a misfortune because it gave no indication of the difficulties to be experienced later in attempting its duplication.

Belem is by no means as far south of the Equator as San Juan is north, but for these two localities the time of occurrence of the wet and dry seasons is reversed. The daily rain in the wet season at Belem, or at least at the beginning and towards the end of the wet season there, was admirably described in 1848 by Mr. H. W. Bates in his "The Naturalist on the River Amazons".

"On most days in June and July a heavy shower would fall at some time in the afternoon, producing a most welcome coolness. The approach of the rain-clouds was after a uniform fashion very interesting to observe. First, the cool sea-breeze, which commenced to blow about ten o'clock, and which had increased in force with the increasing power of the sun, would flag and finally die away. The heat and electric tension of the atmosphere would then become almost insupportable. Languor and uneasiness would seize on every one; even the denizens of the forest betraying it by their motions. White clouds would appear in the east and gather into cumuli, with an increasing blackness along their lower portions. The whole eastern horizon would become almost suddenly black, and this would spread upwards, the sun at length becoming obscured. Then the rush of a mighty wind is heard through the forest, swaying the tree-tops; a vivid flash of lightning bursts forth, then a crash of thunder, and down streams the deluging rain. Such storms soon cease, leaving bluish-black motionless clouds in the sky until night. . . . The following morning the sun again rises in a clouless sky, and so the cycle is completed."

The female *Larra* normally has just such a definite cycle of daily activities. The early morning hours are spent on or in the ground in a search for changas, forced to the surface of the soil by the soaking rainfall of the previous afternoon. When the ground and the vegetation has been somewhat dried by the morning sun, and especially if she has succeeded in depositing one, or two, or even three eggs on as many changas and the stimulus for further search for a host for her progeny has disappeared, she then begins to frequent the flowers from which she obtains nectar. The wasps feed only during the hottest hours of the most intense mid-day sunshine, and even when the usual rain does not occur in the afternoon, rarely are to be noted feeding very long after mid-day. The passage of a cloud over the sun almost instantly stops their feeding activities, which are not resumed again from rest in the depths of a thicket of *Borreria* and other weeds until it is again shining brightly. What the wasps do during rain and at night can not be asserted with certainty: those in captivity mostly rested quietly on vegetation or

on the sides of the container, altho it is possible that some of them may have been burrowing in the sand, or resting quietly in it during part of this time of inactivity.

Mr. Bates' description of the daily shower and the above notes on the activity of *Larra* apply only to normal weather. The wasps are profoundly affected by any deviation, their cycle of daily activities being predicated exactly to a definite time for the rain. At the time the writer first landed in Belem early in February, the downpour came between 1 and 2 P. M. By the end of the week, the time of this daily storm had advanced to noon, and the practical impossibility of continuing the collection of the wasps by the end of that week was caused by the rain beginning in the middle of the morning. The female *Larra* feed at flowers, where they can be collected, from 10 A. M. to noon, and if the rain commences soon after 10, they never reappear at flowers in any considerable numbers that day, even tho later the sun comes out and the vegetation dries off before nightfall. Males may occur on flowers in the afternoon after a shower, and also earlier in the morning, their feeding of course not being disturbed by the necessity for oviposition, which is doubtless the most powerful stimulus determining the activities of the females. It had seemed wise, therefore, to take back to Puerto Rico what wasps had been collected during the second week in February, and to return to Belem for more later in the spring, towards the end of the wet season there, and incidentally towards the beginning of the wet season in Puerto Rico.

As it happened, the time of return was properly timed for May, and the wasps were present then in an abundance comparable to, or even greater than that observed in February. They no longer frequented the flowers of *Borreria* however, but in the same places where collections were made in February, extensive growths of *Hyptis atrorubens* Poit. (as determined by Mr. Otero), a recumbent plant and not noted before, were now knee-high, and their flowers were greatly preferred by the wasps. Little difficulty had been experienced in keeping the wasps alive for several days in February, but in May few of them lived overnight in captivity, and the bulk of them were dead by the second day. This only duplicated the experience recorded by Mr. Williams, who also was in Belem in May and June. Difficulties also were experienced in making the shipments on time, for the planes from the south three times during the month were two days late in their schedule, due to bad weather in crossing the Andes from Santiago. Out of shipments of 70 or 80 wasps eventually

despatched from Belem, only one or two wasps would arrive alive in San Juan. The carefully designed container which seemed to embody every factor essential to the comfort and well-being of the wasps en route was promptly discarded in favor of a much larger one, and with little better results until the final shipment. In the meantime, as the end of the wet season approached, the daily rains came later and later in the day, and sometimes not until after dark—or not at all. On the possibility that the wasps in captivity might to suffering from lack of humidity, their container received an artificial rain under the shower-bath as soon as brought from the field, but with little apparent effect on the mortality.

Incidentally accompanying the rainfall in Belem is a sudden sharp decline in temperature. On the bare possibility that comparable artificial cold might have the effect of keeping the wasps alive, they were placed in an electric refrigerator, and when removed a few hours later all were dead. The manager of the Grande Hotel suggested that he had two refrigerators: the new electrical one for freezing, and the old one using real ice in which the temperature, while considerably cooler than the air outside, never came within 10° or 20° of freezing. Another collection of wasps placed in this old "real ice" cooler early in the afternoon and removed at dark had suffered not a single mortality. All the final collections of wasps were accordingly placed in this old-fashioned refrigerator during the hot afternoons.

But now that a practical method had been found for keeping the wasps alive longer, difficulty was experienced in collecting them. The daily rains ceased to be daily, and for each day that there was no rain, the number of wasps which could be collected in the field was a fifth less than on the previous day. At first this was not serious, but when no rains at all came during the second week in June, it became abundantly obvious that no large numbers of wasps would again be collected for the next six months, or until the beginning of the next rainy season. Out of the final shipment of only 18 wasps however, 7 arrived alive in San Juan: the highest survival from any shipment, and comparable to the first in February in the Wardian cage. The wasps in this final shipment had been refrigerated in the afternoons, and their container placed outdoors at night, including the night preceeding the date of shipment. As there is no stop for the planes north of Belem closer than French Guiana, they usually cover this longest hop at a great height, with the temperatures approximating those of a mountain, and in general, the

planes are comfortably cool while in motion. The only high temperature experienced for any considerable length of time en route, therefore, is in the late afternoon and early evening at Port-of-Spain, and, with present flying schedules, this is hardly capable of alteration.

For the collection of *Larra* wasps in the field, the writer has used a small, non-folding, metal frame net presented by Mr. F. W. Urich, for many years Entomologist of the Department of Agriculture of Trinidad and Tobago. For handling live wasps, one has much greater confidence if wearing a heavy cotton glove on one hand, altho after some experience, one makes sure of the sex of any doubtful individual by letting it attempt to sting, and releasing any unable to prove that they are females. The container at first used in the field was loaned by Mr. K. A. Bartlett, of the Foreign Insect Introduction Division of the U. S. Bureau of Entomology & Plant Quarantine, but it proved quite unsuitable for the shipment of large wasps. That later designed was manufactured in Brazil by a cabinet-maker recommended by Dr. Hagemann, and measured $3'' \times 3'' \times 6''$, with a circular opening slightly larger than one's thumb, stoppered with a cork, in one end, thru which the wasps were transferred from the net. To induce them to enter voluntarily, the slide top had cut in it a hinged door, closely screened inside. By opening this door just before the wasp was released from the net, its violent positive phototropism promptly carried it into the container. The bottom third of the container was partitioned off with coarse wire mesh of such size that the wasps could readily pass, if they desired. This third of the container was mostly filled with moist sand, but prevented from coming out by a layer of wet sphagnum moss next to the wire. The cut ends of *Borreria* or *Hyptis* flowering stalks were thrust thru this wire mesh into the moist sphagnum and sand, and invariably arrived fresh and unwilted at the end of journey in San Juan, according to the testimony of Mr. Seín. Regardless of their theoretical value, few wasps survived the trip to Puerto Rico in these small containers, and eventually their use was restricted to collection in the field, for which they were well adapted when the wire partition, sand and moss were removed, the interior being loosely filled with wet excellsior and a few flower blossoms. The larger and much simpler shipping cage used for later consignments had only a $5'' \times 8''$ wire screen window in its sliding top. The transferrence of the wasps from the collecting cage to the shipping cage, or to the Wardian cage, was always attended with difficulty, and whatever method was used, before the operation was completed, one invariably wished he

had used some other. At first it was conducted in bed with the mosquito bar tucked in securely on all sides, and later, at night in the bath room from which everything movable had been removed. By sliding back the tops of the two containers so that their openings were opposite, the moist excellsior in which most of the wasps had come to rest could be droped into the shipping cage, but some invariably chose to remain in the field cage, and others became active and escaped where the openings of the two cages did not exactly meet. In such an extremity, a gloved hand might recover those which hid in the folds of the mosquito bar, or which did not at once escape, despite the darkness outside, thru cracks around the door. The bottom of the large shipping cage was covered with a thin layer of moist sand, into which the cut ends of the flower stalks were thrust, and naturally such cages had to be kept right side up, but the superior survival of the wasps in the larger containers much more than justified the trouble of getting the wasps into them, and the greater care that had to be taken of them en route. To prepare for delivery to the plane, several thicknesses of toweling were tied over the screened window, and saturated with water so as to arrive still damp two days later

Mr. Williams has recorded the finding of *Larra americana* in lesser abundance at more southern localities in Brazil, and of other species of mole-cricket parasites in Equator. Such records are valueless in considering localities from which shipments might more readily be made to Puerto Rico, but at least indicate a wide distribution of such parasites. To determine if *Larra americana* might not occur at localities even nearer to Puerto Rico than Belem, the writer stopped at Paramaribo, Dutch Guiana, on his return in June 1936. Plants of *Borreria* were not noted, but quite extensive beds of *Hyptis* were found at the end of a country road "Charlesburgstraat" in a clearing at the edge of the forest, and feeding on the nectar of their flowers were females of *Larra americana*. If the insect ocurs north of the Amazon River, it presumably is present in all suitable sandy regions of tropical South America. The last stop of Pan American Airways on the continent before reaching Trinidad is Georgetown, British Guiana, but the soil here, unlike that around Paramaribo, which is sandy swamp, is mud. Even where it becomes somewhat coarser in texture, neither of the plants frequented by *Larra* for nectar was noted, altho mole-crickets are present in small numbers in the sandy foreshore outside the seawall, and to a lesser extent in the golf course at Belair, in the outskirts of Georgetown. A day's

journey into the interior and they become abundant, for Mr. T. A. W. Davis, Forester at the Mazaruni Station, reports them a serious pest in his nurseries, the specimens submitted by him being both *Scapteriscus vicinus* and *Gryllotalpa hexadactyla*. Thus, British Guiana is indicated as being no nearer Puerto Rico, from the standpoint of transporting the wasps, even if they do occur there, than is Belem. Dutch Guiana remains a definite possibility, altho lack of local transportation, and the limited area where *Hyptis* was noted there, makes Belem still the more desirable locality for the continuance of the attempt at the introduction of a parasite of the changa into Puerto Rico, and the beginning of the rainy season the most favorable time.

Normally, the beginning of the rainy season in Belem is sometime in December, usually between Christmas and New Year's Day. In 1936, the first rain, after an unusually long, hot and uninterrupted dry season came on December 28th, the day that the writer left San Juan by plane, so that some wasps were available for collection when he first arrived in Belem. But the rainfall in the first three weeks of January consisted of showers so light as to barely moisten the surface of the ground, so that by the middle of the month only a few *Larra* were to be seen, and most of these were males. The first general and heavy rain was on January 17th, 1937, continuing all that day and night and most of the morning of the 18th, the air being alive with winged termites much of this time, and on the second night tremenduous numbers of adults of the common large black cricket, *Grillus assimilis* F., invaded the better lighted sections of Belem. The morning of the 19th was bright and clear and the females of *Larra* suddenly so abundant that one could not keep track of the number collected. Yet out of the 30 or more collected just the day before shipment and sent in the large container by the fast Clipper, making stops only at Paramaribo and Port-of-Spain, and arriving in San Juan before 10 A. M. on the morning of the 21st, only 6 or 7 were alive when received, and only 2 survived to be released at Malesa Sub-Station at Isabela, where the ground was being irrigated every day to bring changas to the surface and *Borreria* was specially grown to ensure optimum conditions for the wasps. The heavy mortality could not be due to a hot afternoon, for the rain came at 2 P. M. on the 19th, and lasted all night. The container was kept during the night on a window-ledge on the third floor of the Hotel Grande, and not delivered for transportation until the morning of the departure of the plane, at which time, so far as could be determined, it was in good condition. What happens to

shipments en route is a matter of conjecture, but the spraying of the planes with pyrethrum insecticide just before arrival in San Juan certainly is most unfortunate from the standpoint of keeping the *Larra* wasps alive. For later shipments, the purser or steward of the plane was personally interviewed in Belem just before the shipment was delivered, and instructions given, in addition to those written on the tag, to pour ice-water on the toweling covering the screen window of the container before landing in Port-of-Spain, to keep the shipment out of the sun after arrival and in the shed at the end of the pier until the following morning, and to keep it in the tail of the plane when the plane is being sprayed at San Juan. So far as can be determined, all the special care had little effect in increasing the survival of the wasps, that of some shipments being most discouragingly low. On the other hand, one shipment of 36 wasps sent by the slow plane from which release could not be made until the following day at Malesa, had 7 wasps alive and active at that time, and the final shipment of 16 wasps, in a container of twice the size of those previously used, with three windows, by the fast plane, had 5 wasps alive for release at Maleza. But the total of 28 wasps received alive out of almost ten times that number collected is a most disheartening record (see Table), relieved only by the assurance that all of these were females and that they were released where changas were not only abundant, but where the daily irrigation surely made them readily available for attack and oviposition, and where *Borreria* was present in abundance.

The mortality of *Larra* was so heavy on the slow planes, with the one most extraordinary exception above noted, that discontinuance of using them was contemplated as soon as the reports began to be received. The slow planes arrive in Trinidad, however, almost as soon as the fast planes do, and as Mr. Pickles was keenly interested in attempting the introduction of *Larra* in Trinidad, and indeed had attempted to rear the parasite there from the first trial shipment made to him in February, 1936, he was asked to receive shipments of the wasps, either for release or rearing. Just at this time, however, he was in the hospital recovering from an operation, consequently Mr. Adamson received the shipment. Out of 27 females sent from Belem, 7 were alive upon receipt, of which 5 were still alive the following morning, when they were placed in individual tubes or petri dishes and supplied with mole-crickets. Before the last one of these had died, Mr. Adamson had secured 21 eggs, and, at last report, several of the eggs had successfully hatched after 9 days incubation.

SHIPMENTS OF *LARRA AMERICANA*, BELEM TO SAN JUAN, 1937

Sending No.	Type Cage	Weather	Wasps Col.	Date Left	Type Plane	Date Arr.	Wasps Alive	Wasps Dead	Wasps Total
1.....	Small.	Too dry	21	Jan. 3...	Slow....	Jan. 4...	None....	21	21
2.....	Small.	Too dry	14	Jan. 6...	Fast....	Jan. 7...	3	15	18
3.....	Small.	Too dry	17	Jan. 13..	Fast....	Jan. 14..	1	20	21
4.....	Small.	Too dry	5♂7♀	Jan. 17..	Slow....	Jan. 18..	None....	Not Counted	
5.....	Large.	O.K....	Many ♀	Jan. 20..	Fast....	Jan. 21..	2	Not Counted	
6.....	Large.	O.K....	20♂32♀	Jan. 25..	Slow....	Jan. 26..	2	50	52
7.....	Large.	Cloudy.	8♂12♀	Jan. 27..	Fast....	Jan. 28..	4	21	25
8.....	Large.	O.K....	36♀	Jan. 31..	Slow....	Feb. 1...	7	29	36
9.....	Large.	O.K....	29♀	Feb. 3...	Fast....	Feb. 4...	2	27	29
10.....	Large.	O.K....	27♀	Feb. 7..	Slow....	Feb. 8...	None....	27	27
11.....	Large.	Cloudy.	17♀	Feb. 10..	Fast....	Feb. 11..	2	15	17
12.....	Extra large	Cloudy	17♀	Feb. 17..	Fast.....	Feb. 18..	5	11	16
A to Trinidad	Large.	O.K....	27♀	Feb. 15..	Slow....	Feb. 15..	7, 5 on Feb. 16th, all used in breeding in laboratory	20	27

Except for the one collection of January 19th, 1937, on no other day during January and February of this year were so many wasps collected as on many days during May 1936. Possibly this may have been due to the effect of intensity of the dry season of 1936, or it may merely be due to the fact that no males were collected after the rains had started in 1937, and the wasps were in reality quite as abundant as previously. While the total number collected during a day often was almost as high as in May, the effort and time spent in the field was much greater, and when the daily rains did not come until 2 or 3, or sometimes 4 P. M., the wasps rarely appeared in any numbers during the morning, the bulk of the collection of females being made from noon up to within a few minutes before the breaking of the storm. Few mornings were of uninterrupted sunshine, scattered clouds beginning to appear often just at about the time when the wasps were to be expected, and increasing in number and density as the day advanced so that the wasps found but few intervals in which to fly about and feed in full sunshine. Apparently they can not see as well when the day is cloudy, and certainly they are not as active, wary and hard to catch, even tho fewer of them are available to be caught.

All collections were brought to a sudden termination in Belem by the middle of February by the sudden concerted activity of the municipal authorities in cleaning up the city after carnaval, which consisted in cutting the weeds, not only on the streets in the city, but far out beyond the city line along the railroad tracks where the bulk of the collections were being made. The mowing down of these

dense thickets of *Borreria* did not serve to concentrate the wasps on the few clumps left, for beyond the built-up part of the city, the forest surrounds it on all sides not bounded by the rivers. There are no waste lands or abandoned areas; clearings or burned-over areas in the forest are planted to yuca, or grow up so rapidly to high second growth that *Borreria* has no chance to become established, and in reality the only favorable places for it are along the too-wide roads of the outskirts of Belem, or along the railroad track. The weather also at this time was rapidly becoming less favorable to *Larra*, entire days being cloudy and misty, interrupted, not by sunshine, but by showers, so that even while good collecting areas were still available, the number of wasps that could be collected was rapidly diminishing.

In normal years, Dutch Guiana has a short rainy season during December and January, so that growths of *Hyptis* should be at their height in February, and Larrid wasps abundant. During the one week spent there in February 1937, two wasps were seen, for there had been no short rainy season this year. *Hyptis* growth was still recumbent, but by riding on a bicycle to the end of every road around Paramaribo, its areas of abundance could be located and plotted, for use at times when wasp collections might be made there.

The dishearteningly small number of *Larra* surviving the journey from Belem to San Juan in January and February 1937 seemed to indicate the desirability of finding some closer point of collection, the shorter journey from which might enable more of the wasps to survive. To be sure, Paramaribo, Dutch Guiana, is considerably nearer San Juan, but the airport is so far from points where *Larra* is found that no collections would be possible on the day of shipment. Since Georgetown, British Guiana, is unsuitable, the other points in South America which might be considered are the airports of Venezuela. The one nearest to Trinidad is the oil-field at Caripito, the next is Guanta, the port of Barcelona, both with such frequent airplane service that wasps collected at either point would reach San Juan by the next morning. A personal inspection of Guanta and Barcelona in April 1937 immediately indicated their unsuitability, the area in the vicinity of Guanta being a desert, and Barcelona is hours away by automobile. The presence of *Borreria verticillata* along the banks of the river beside Barcelona might indicate the possible presence of *Larra* during rainy weather, but at the time the survey was made there had been no rain for some weeks, and the presence of adults was not to be expected. Caripito is a clearing in the midst of virgin forest of the Orinoco delta region, rainfall is normally

considerably more abundant than at Barcelona, and *Borreria verticillata* grows in abundance on the sandy soil of the landing field of the airport. April, however, is a month of drought for Caripito, and the only hope of collecting *Larra* was to return in the summer, when the greatest abundance of rainfall is to be expected.

Mr. Luis F. Martorell spent part of August 1937 at Caripito, but despite the apparent suitability of conditions, he collected only a few small *Larra americana* (as determined by Miss Grace Sandhouse), the wasps being so scarce that making shipments of live adults to San Juan was out of the question at that time. His collections and the definite determination of the specimens, however, establishes the record of *Larra* for Caripito, and its scarcity at the time he was there by no means proves that it might not be abundant in other years when total rainfall is more abundant than it was in 1936–37. Caripito remains a possibility to be further investigated if others fail.

The doubtful record of the presence of the changa in Haiti was assumed to refer to *Gryllotalpa hexadactyla* Perty, when the Cuban mole-cricket was definitely determined to be that species. In the summer of 1937, Mr. André Audant, Entomologist in Haiti for the Service National de la Production Agricole et de l'Enseignment Rural, sent a specimen of a mole-cricket collected by a student to the U. S. National Museum for determination. Mr. A. B. Gurney, the specialist in Orthoptera there, identified it as *Scapteriscus vicinus* Scudder, and Mr. Audant, knowing of our great interest in this insect, promptly reported the determination to us. To determine whether the scarcity of the Puerto Rican mole-cricket in Haiti was due to control by a parasite, two weeks in November and December 1937 were spent there. In Mr. Audant's automobile, nothing of interest was noted driving northwest from Port-au-Prince to St. Marc and in the valley of the Artibonite, but on the second day going west towards Petit Goave, three live changas were collected in a sandbar in the bed of a stream. This is the first definite locality collection of *Scapteriscus vicinus* in Haiti.

The greater part of Haiti is mountainous in character, the central plain of the Cul-de-Sac being heavy clay, and most of the stream deltas consist of loose rocks and bowlders, succeeded immediately by clay, with no intermediate sandy area where the changa might find conditions suitable for its existence. Thus the sandy stream bed at Petit Goave, where these changas were found, in reality is quite exceptional for Haiti.

An exceptionally complete herbarium of the plants of Haiti is to be found at the Damien office and school of agriculture, having been assembled by Dr. Erik Ekman of Uppsala, Sweden. He collected specimens of the two plants at the flowers of which *Larra americana* is most commonly found in Brazil: *Hyptis atrorubens* between Port Margot and Bayeux on the north coast, and *Borreria verticillata* at Morne Brouet, south of Kenscoff, at an elevation of 1,600 meters. As Ekman was more likely to collect from relatively inaccessible localities, rather than in those more readily reached by automobile, to search for *Borreria* in the region where he found it required several days of travel afoot. The mountains between Port-au-Prince and Kenscoff were tramped over one day, and three days were spent at Kenscoff, and on one of the mountains south of Kenscoff, at an elevation of possibly 1,700 meters, large clumps of an undetermined species of *Borreria* or *Mitracarpus* were found. They were growing mingled with such temperate zone plants as blackberry, mullein, wild carrot, narrow-leaved plantain, dandelion, St. Johnswort, chick-weed and white clover. Hours were spent watching them during the middle of the day in bright sunshine, but no wasp even remotely resembling *Larra* was noted. Considering the low temperature (except in full sunshine), and the soil, which is a heavy clay, the absence of *Larra* is hardly surprising, and further search in the Kenscoff mountain region was discontinued.

The only sandy beaches in Haiti near Port-au-Prince, aside from those previously investigated towards St. Marc, are on the southern coast of the southern peninsula. A one day trip to Jacmel was most disappointing in its results, the only sandy beach being just at the city, and used for a public dump. A two day trip to Cayes showed little more of tangible value, for the beaches between Aquin, St. Louis du Sud and Cayes are comparatively narrow, and back of them the soil is clay, with bare rocks or steep mountains rising close behind. The sand bar across the mouth of the river at Cayes is extensive, but neither *Hyptis* nor *Borreria* grew there. No trace of the changa was noted, altho rain of the day of going would have made its presence visible the next day coming back if it had been at all abundant. Thus the net result of three days travel over rough roads was entirely negative: no changa and no plant on the flowers of which *Larra* might be expected to occur, altho conditions of temperature and rainfall, and soil for limited areas, would appear to be somewhat more favorable than in the region nearer Port-au-Prince.

While the period spent in Haiti was too short to eliminate all possibilities, it would appear that in the area which may be reached by automobile in a day from Port-au-Prince, the changa occurs in very limited regions, and the plants at which *Larra* is found in Brazil do not occur at all. The scarcity of the changa is thus presumably due to the limited environment in which it can occur, and not due to the presence of a specific parasite.

The possibilities of collecting *Larra* at points nearer by airplane to San Juan having been temporarily or entirely eliminated, refinements and improvements in methods and technique from Belem still remained to be tried, and in the middle of January 1938, Mr. Luis F. Martorell proceeded to Brazil. During the few days less than a month that he was there, six shipments of *Larra* were made, and one was brought with him, small in number of *Larra* adults as compared with those of previous years, due to unfavorable and abnormal weather in Belem, but otherwise the most successful of any yet made. The weather during January and February 1938 was also most abnormal in Puerto Rico, being especially favorable for the introduction, and releases could thus be made less than half an hour from the San Juan airport, in an extensive sandy area to the south of the Laguna de San José which is most nearly comparable in Puerto Rico to the region from which *Larra* comes in Brazil. The releases were made beside an acre previously in cultivation which is now almost a solid mat of *Hyptis atrorubens,* while high plants of *Borreria* are numerous in near-by pastures and areas not in cultivation. During the time that the shipments were being received, the weather of this region, while not exactly the same as Belem at this time of year with rains early in the afternoon, was sufficiently similar in essentials, for in Puerto Rico the rains came nearly every night or early morning, with the middle of the day bright and clear. The exceptional weather in Puerto Rico this winter is a very important factor favoring the success of the introduction.

In regions where mole-crickets are abundant in Trinidad and Puerto Rico, many of them will come to light on rainy nights, but none was thus noted by the writer at Belem during the months spent there. Mr. Martorell was determined to obtain at least a few specimens, and going out at night with a flashlight and a boy to dig, succeeded in obtaining several on the first attempt. The boy subsequently obtained many more, for which he was paid at the rate of 3 cents for each specimen. Mr. F. X. Williams has related how he induced *Larra* wasps to attack and parasitize mole-crickets

in captivity, and Mr. Martorell, using similar methods of introducing the wasp into a small tube with the changa, and shaking them up together if the wasp at first showed no interest, succeeded in obtaining many artificially parasitized mole-crickets. In all shipments except the first two, such parasitized changas were sent to San Juan with the wasps, and one shipment consisted only of such *Larra* in the egg stage. Some of the changas died en route, but over three-fourths of them survived the journey and the close confinement, and most of these were released upon arrival. Of those which were retained in the laboratory, eggs which had been laid previous to January 26th hatched within a few days after receipt, and had grown to full sized maggots by two weeks later (February 14th), the air temperature recorded beside them during this period varying from 72° to 78°F. Only one maggot, however, succeeded in forming a cocoon, and even this one died before transforming to adult. The weight of cocoon and contents was .3145 gr., but this is not net, as it includes grains of sand stuck in the viscous dark brown plastic of which it was composed, which could not be separated out.

The live weight of a changa is .78 gr., its air-dry (dead) weight .287 gr., and subtracting from this the heavily chitinized remains not available for consumption by the parasitic maggot which weighed .077 gr., gives .21 gr. as the net air-dry weight of the food eaten by *Larra* in its parasitic stage. The air-dry weight of large *Larra* females is .0524 gr., and of *Larra* males .022 gr., thus it would appear that the food eaten by the *Larra* may be as little as four times for females, or as much as ten times for males, as the weight of the adult which it becomes. It is much more likely that parasites on the largest changas become females, while smaller changas or large nymphs furnish only food sufficient for the development of males, and the efficiency in the consumption of food by the larval *Larra* is substantially that previously determined by the writer for other parasitic insects (**16**).

In keeping the changas in individual cans with sand and corn, no mortality of the host is experienced after those injured in transit have died, but eggs or maggots are easily killed or dislodged in attempting to examine the active changas for their presence. Thus, only the parasitized changas of the first shipment were retained in captivity, mostly to determine the rate of development of the parasite, and all subsequent parasitized mole-crickets were released in the field. Of the total of 121 parasitized changas sent from Belem, 95 arrived in San Juan alive, and of these, 79 were released in the field at the same time as the wasps.

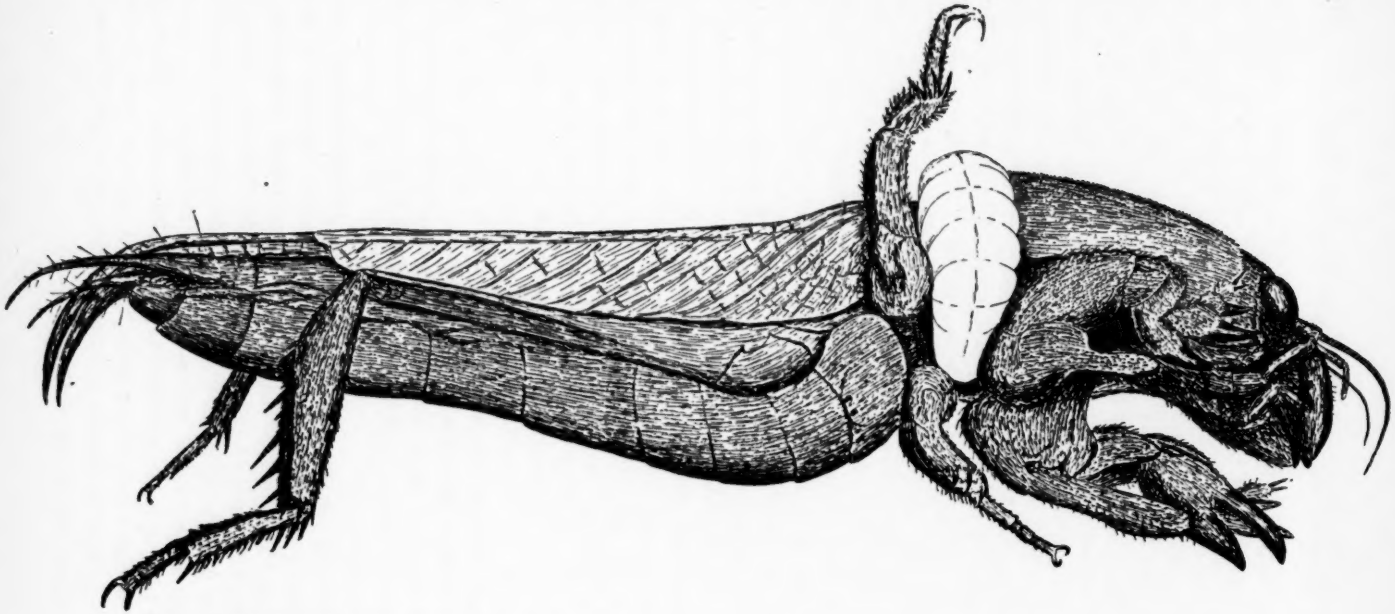

FIG. 4. Maggot of *Larra americana* feeding on the juices of a "changa" killed by it. (Drawn by F. Sein.)

Quite aside from the number of *Larra* thus introduced in the egg stage, the presence of the parasitized changas in the box with the wasps had a most surprising effect in greatly reducing their mortality. In the first two shipments made without changas accompanying, only one wasp arrived in San Juan alive; of the succeeding shipments which had a screened box or can of parasitized changas, the first contained 11 live wasps, 1 weak and 6 dead, the second contained 18 live wasps and only 1 dead, the third had 9 live wasps and only 2 crushed under the box of earth and changas, while the final shipment brought by Mr. Martorell in person, but delayed en route an additional day at Trinidad, had 7 live wasps and 4 dead. This is so much better than any previous series of shipments as to indicate that the presence of live changas is quite essential for keeping the wasps alive en route, and will of course be used in all future shipments. It appears to be the key to the problem: the solution of how to get the wasps alive from Belem to San Juan. The total number of wasps sent by Mr. Martorell this year was 81, of which 35 arrived dead and 46 alive, as compared with 262 shiped last year, but of which only 28 arrived alive. The difference in the total number indicates the much less favorable weather in Belem for making the collections, while the much larger proportion of wasps arriving alive shows the more successful method of shipment accompanied by changas. The total of only the shipments accompanied by changas is even more clearly indicative of the success of this method: 59 wasps sent, 45 arrived alive, with only 14 dead.

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NEW SPECIES OF *NEMOCERA* FROM PUERTO RICO

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During the months of February and March 1935, Dr. J. G. Needham of Ithaca, New York, in company with Dr. Julio García-Díaz of Río Piedras, P. R., collected numerous insects on the island of Puerto Rico, a collection which was considerably augmented later in the season by Dr. García Díaz working alone. Of the Diptera obtained several of the nemocerous families were placed in my hands for identification. Owing to the fact that it was necessary to collect the specimens in alcohol several of the Psychodidae could not be identified. This was true also of some species of other families where represented by females or defective specimens alone. A list of the more striking captures as well as descriptions of previously undescribed species are given herewith.

CHIRONOMIDAE

Pentaneura marmorata n. sp.

♀. Head and antennae pale yellow, apical antennal segment, the elongate palpi and mouthparts infuscated. Twelfth segment of antenna three times as long as the eleventh segment. Thorax and scutellum pale yellow, mesonotum with four broad brown vittae; lateral margins of metanotum and of pronotum brown; pectus largely brown; pleura with about ten irregular brown spots of varying sizes. Abdomen pale yellow, tergites 3, 4 and 5 each with a large rectangular brown spot. Legs yellowish white; extreme bases of coxae, a spot on trochanter, a preapical ring on each femur, a ring near base of each tibia and the extreme tips of the tibiae and of the metatarsi, brown. Fore basitarsus scant 0.6 times as long as the tibia, pulvilli absent. Wing marmorated with brown spots as follows: an irregular rectangular spot covering humeral crossvein and arculus; an irregular triangular spot covering the r-m crossvein, extending to the costa; a large brown rectangular area extending from the tip of R_1 to apex of wing covering the costa and the media, this area with a small hyaline spot along the costa between R_1 and R_2; a large irregularly 4-branched hyaline spot between radius and media, and another less distinctly margined irregular hyaline spot near apex of the wing; in the basal half of cell R_5 and just beyond the r-m crossvein with three small dark brown oval spots of which the more distad is the smallest; m-cu crossvein covered in part by a small spot, distad of which in cell M are about four more or less square spots, the apical one containing a vaguely margined hyaline spot; Cell C_1 with two minute basal spots, a square spot filling the space above apex of Cu_2 and the cell apically brown margined; behind the cubitus there are about three

small spots basally, a large square spot under the base of Cu_2 and distally filling the margin under the apex of Cu_2, an irregular brown area containing an indistinctly margined hyaline spot. The larger wing spots are more or less contiguous with one another. Squamae fringed. Halteres white. Length 2.5 mm, wing 2.4 mm.

Type from Río Cidra, Puerto Rico, March 23, 1925. In the Cornell University Collection.

Pentaneura monilis L., var. *peleensis* Walley.

Taken at light, Tortuguero Lake, August 15, 1935.

Coelotanypus insulanus n. sp.

♀. Head and antennae yellow, apical antennal segment brownish; eyes slightly emarginate, separated at vertex by a width equal to the distance between the bases of the antennae; thorax including scutellum reddish brown; pleura yellow, metanotum dark brown; mesonotum without acrostichals, the pimple on disc, small. Abdomen yellow, tergites 2 to 7 with basal half or two-thirds, brown, eighth tergite and sternite more or less brown. Femora yellowish, apical sixth dark; tibiae yellow, bases of fore and hind pairs and apices of all of them brown; fore tarsi broken off, the apices of the first and second segments of middle and hind tarsi yellow, their apices and the whole of the remaining segments dark brown. Fore tibiae with one, middle and hind tibiae with two spurs. Wings hyaline, veins yellow, r-m crossvein dark brown; petiole of cubitus about half as long as the m-cu crossvein; anterior branch of the cubitus slightly undulate. Squama fringed. Halteres yellow. Length (in alcohol) 2.2 mm.

Yúnez River, Puerto Rico, August 11, 1935. Type in the Cornell University Collection.

Coelotanypus concinnus Coquillett.

Taken at light. Cartagena Lagoon, August 9.

Cardiocladius obscurus Johannsen

Taken at light, Cartagena Lagoon, August 9.

Cricotopus aberrans n. sp.

♀. Head yellow, occiput, antennae and mouth parts slightly darker. Eyes pilose, widely separated on the front. Antennae with six segments of which the last is three times as long as the fifth. Thorax yellow, with the three broad vittae on mesonotum, the scutellum and metanotum, brown. Abdomen yellow, the apical half of the second tergite the whole of the third, and the sixth, seventh, eighth and ninth tergites except narrow bases, brown. The terminalia, which are white, resemble those figured for *Orthocladius absurdus* (N. Y. State Museum, Bull. 86, Plate 33, 7) with about five strong bristles at apex of each

lobe. Femora whitish with apical third dark brown; fore tibiae white, apical third dark brown, the other tibiae yellow, extreme base of second pair and basal third of hind pair more or less brownish; fore tarsi wholly dark brown, middle and hind tarsi infuscated toward the tip; pulvilli lacking; empodium long; fore basitarsus 0.6 times as long as the tibia. Wing hyaline, veins yellowish, costa produced, cubitus forks distad of the crossvein. Squama not fringed. Halteres white. Length 1.8 mm.

Type from Tanamá River, Puerto Rico, March 12, 1935.

Paratypes from the same locality March 12, 13 and May 11; from Yúnez River, Feb. 27, and Cagüitas River, March 3, 1935. Type in the Cornell University collection.

The color of the middle and hind tibiae in the paratypes shows some variation.

The *Orthocladius absurdus* Joh. noted above will fall in *Cricotopus* as defined by Edwards in 1929. *Cricotopus insolitus* Curran also from Puerto Rico has a similarly constructed terminalia but they are here relatively more slender and elongate than in *C. aberrans* and *absurdus*.

Cricotopus conformis Curran.

Taken at light, Yúnez River, Febraury, June; Tanamá River, March, July; Río Cidra, March; Lares, March; Quebrada Joba, March, 1935.

Cricotopus insolitus Curran.

Taken at light, Río Cidra, June; Yúnez River, February, June, August; Luquillo Mts., June; Tanamá River, March, 1935.

Corynoneura (Thienemaniella) similis Malloch.

Taken at light, Yúnez River, June, August; Río Cidra, March, 1935.

Pseudochironomus fulviventris Johannsen

Taken at light, Yúnez River, June 22; Luquillo Mts., June 10, 1935.

Chironomus *(Stenochironomus)* **furcata** n. sp.

♂. Head and antennae yellow, the scape, palpi and proboscis pale brownish. Eyes separated on the front by a width greater than the width of the dorsal process of the eye. Last antennal segment 1.5 times as long as segments 2 to 13 combined. Palpi nearly as long as the last antennal segment, its second and third segments subequal, fourth segment 1.5 times as long as the third. Thorax yellow, the two broad lateral vittae of the mesonotum, base of scutellum, metanotum except for fine median yellow line, three large angular spots on the pleura, and two large spots on the pectus, brown. Thorax produced

over the head and pronotum reduced as in Stenochironomus. Abdomen yellow, the larger part of the first and the apical third or half of third to sixth, and larger part of the remaining tergites brown. Spur of the ninth tergite long and slender the tip extending caudad to tips of the inferior and superior appendages, the latter slightly enlarged apically with strong anteriorly directly bristles and one long posteriorly directly bristle; the superior appendage enlarged and bristly at base, slender, bare and curved apically. Dististyles bristly, longer than the basistyles, gradually widened apically, ending in a fork the inner limb of which is stout, blunt, and thumb-like, the outer limb longer more slender and tapering to a point on which a long slender bristle is placed. Legs yellow, fore tarsi not bearded, fore basitarsus 1.2 times as long as the tibia; pulvilli well developed; fore tibiae with rounded scale; middle and hind tibiae each with two strong spurs on normal combs. Wings hyaline with pale veins including crossvein; the radius ends as far in front of the apex of the wing as the media does behind it; cubitus forks distinctly distad of the crossvein. Squama with a fringe of several hairs. Length 3.5 mm.

Taken at light June 7, 1935. Type and paratypes from Luquillo Mts., Puerto Rico. The lack of wing bars combined with the peculiar furcate distictylesc distinguish this species from other members of the subgenus Stenochironomus. Type and paratypes, Luquillo Mts., June 7, 1935. Type in the Cornell University Collection.

Chironomus bulbosa Garry.

This species was originally described from Cuba. Guánica Lagoon, February 24; Yúnez River, June 19; Cartagena Lagoon, August 3 and 10; Tortuguero Lake, August 15.

Tanytarsus (Rheotanytarsus) meridionalis n. sp.

♂. Pale yellow, including legs, the metanotum and the three vittae of the mesonotum darker yellow. It is probable that in life the abdomen, at least, is somewhat greenish. Eyes separated on the vertex by a distance subequal to the width of the dorsal extension of the eye. Antennal segments 2 to 13 combined about 1.75 times as long as segment 14. Hypopygium closely resembling that figured in New York State Museum Bulletin No. 86, plate 33, 4; the apical fifth of dististyles curved down, about a fourth as wide as the dististyles near the middle; dorsal spur of ninth tergite acute, ending a little distad of apex of basistyle; inferior appendages slightly clavate ending beyond tip of the spur, with the usual strong curved bristles; superior appendages shorter, ending little if any distad of apex of basistyle, apical and distinctly broader than toward the base with a few fine erect bristles; brush slightly shorter than superior appendages, with apical half or two-thirds with flattened blade-like hairs which are broadest at the tip. Anterior tibia with a short sharp spur, fore basitarsus about 2.3 times tibia in length; middle and hind tibiae each with two combs which are separated from each other at the base by a distance nearly half the depth of the comb; each comb with a long, sharp, slightly

curved spur; pulvilli vestigial; empodium small. Wings hyaline with pale veins; rather densely hairy; posterior branch of radius ends but very slightly distad of anterior branch of the cubitus; media ends in the tip of the wing; cubitus forks far distad of the short cross vein. Length 1.70 mm, wing 1.25 mm.

♀. In coloring like the male. Antennae seven segmented, the second and third more or less fused, the intermediate segments spindle-shape, without distinct necks, the last segment slender, scarcely twice as long as the next to the last. Ratio of fore tibia to basitarsus as in the male. Wing slightly broader than in the male. Length 1.25 mm. Wing length 1.25 mm.

This species differs from the North American *T. exiguus* Joh. and from the South American *T. abbreviatus* Kieff, in the relatively longer fore basitarsus and the relatively shorter terminal antennal segment in the male.

Type and paratypes from Yúnez River, August 14, 1935. Other localities: Río Cidra, March 23; Luquillo Mts., June 10; Tanamá River, March 12; Quebrada Jobo, March 7; Tortuguero, March 19, 1935. Type and paratypes in the Cornell University Collection.

Ceratopogon (Brachypogon) impar n. sp. (Ceratopogonidae)

♀. Thorax including scutellum and metanotum black, slightly cinereous, notum sparsely short bristled; abdomen yellow, third and fourth tergites each with a pale brown median transverse band interrupted and darker in the middle; fifth and sixth tergites show a trace of an interrupted band in the form of two dark spots place side by side; apex dark; venter yellow. Antennae yellow, scape dark. Legs yellow, basal half of fore and middle femora and extreme apex of all of these, dark; claws equal. Wings milky, without microtrichia; apex of radial veins fused into a conspicuous dark stigma ending about the middle of the wing but slightly distad of the level of apex of Cu_2; media ends slightly behind apex of wing. Halteres pale. Length 0.8 mm in alcohol; wing 0.7 mm.

The coloring of the abdomen and legs seems to be subject to some variation since in the paratype the paired marks on the abdomen are fused on the middle line and the middle and hind tibiae are slightly darkened in the middle section.

This species differs from the European *C. vitiosus* in coloring and in the relatively shorter radial veins. Type from El Yunque trail, June 10, 1935; paratype from Luquillo Mts., June 7, 1935. In the Cornell University Collection.

Paltostoma agyrocincta Curran (Blepharoceridae).

Sabana River, March 7; Luquillo Mts., June 7; La Mina Recreation Area, July 14; El Yunque Trail, July 27.

Key to North American species of Maruina (Psychodidae)

(Based largely on descriptions)

1. Basal sections of R_3 and M_2 obliterated and lacking hairs; wing narrow lanceolate, about four times as long as wide; R_3 originates distad of the level of the base of M_3; hairs of body and wings brown, hair tufts on thorax and wing base blackish brown. Puerto Rico----*hirta* n. sp.
   Basal sections of R_3 and M_2 distinct, or differing in other characters----- (2)
2. Thorax with black or brown hairs; antennae three-fourths as long as width of wing; legs black, basitarsi white; ventral plate elongate, narrowed toward the base. Length of female 2 mm. California and Washington----*lanceolata* Kinkaid
   Thorax largely with yellow hairs----- (3)
3. Legs uniformly blackish brown; wing with blackish hair, basal part to the fold with whitish hair. Male. Maryland----*nuda* Dyar
   Legs more or less pale----- 4
4. Antennae nearly as long as the body, segments beyond the second over three times as long as broad; petiole of R_3+_4 less than half as long as the cell R_3; petiole of M_1+_2 less than a fourth as long as the cell M_1; body and legs covered with yellow hairs; length 1 mm. Female. Mexico----*cirrata* Coq.
   Antennae shorter; wing with white tuft at tip----- 5
5. Hair of abdomen pale, slightly mixed with blackish; wing uniformly covered with black hair; length 1 to 1.25 mm. Female. St. Vincent Island----*angustipennis* Will.
   Hair of abdomen darker, clothed with short black and white, and longer dark hair; tip of ventral plate narrow with shallow emargination and rounded lobes; wing with two transverse black bands; length of wing 2.5 mm, breadth 0.45 mm. Arizona----*unipunctata* Haseman

Maruina californiensis Kellogg cannot be included here since only the immature stages are known. The species *californica* Kinkaid does not belong to the genus Maruina; M. *cirrata* is placed in the genus on the authority of Dr. Dyar.

Maruina hirta n. sp.

♂. Hairs on head, body and wings coarse, flattened, scale-like. Hairs on head brown with blackish-brown tufts on each side above the eyes; slender hairs on first basal and on the seven apical antennal segments pale brown, the remaining antennal segments shaggy with somewhat broader, closely crowded blackish-brown hairs. Antennae 0.6 mm long, the segments short ovate, without distinct necks. Eyes separated on the vertex by nearly three times the width of the eye-bridge. Ground color of thorax and abdomen pale; a dense tuft of blackish hairs anteriorly on mesonotum on each side, remainder of thorax, abdomen and legs more sparsely covered with brown hair. Tarsi pale, sparsely short haired, apical segment dark. Each wing with a dense tuft of long, blackish-brown scale-like hairs on the costa proximad of the fold and another tuft of the same size just distad of the fold, wing veins with long brown hairs, costal and hind

margin with a dense fringe of long brown hairs, that on the hind margin measuring 0.6 to 0.7 mm in length. The wing membrane as seen in the denuded wing is tinted pale brownish with a hyaline patch distad of the middle and more or less hyaline basally, in cells R_5, M_{1+2} and the anal angle. The venation somewhat resembles that figured by Haseman (1907) for *M. unipunctata* Has. but the bases of R_2 and M_2 are obliterated. It resembles still more closely that figured by Müller for *M. pilosella* Müller (1895) differing in that R_2 is about as long as the petiole of R_4 and R_5, and also that the interruption at the bases of R_2 and M_2 is more extensive. Wing about four times as long as wide, apex acute as in *M. unipunctata*. The halteres are pale.

The hypopygium is of the usual Psychodid type; minor appendages hairless, well developed, the basal segment more or less cylindrical, more than twice as long as wide, the apical segment a little shorter, but more slender and tapering to the apex. Basal segment of major appendages pear-shaped, basally with twenty or more long, slender, erect hairs; apical segment about .035 long, capitate, the head-end with small dark scales, the petiole much attenuated and bare. Last sternite (dorsal in position) slightly longer than broad, parallel sided, apex truncate with rounded angles. Ninth tergite (ventral in position) slightly broader than long with median somewhat truncated lobe between the short, rounded lateral lobes. Length of insect 1.6 mm; wing lenth 1.3 mm.

♀. Like the male except for sex characters. The palpi are 0.3 mm long, the apical segment 0.125 mm. The shaggy tuft of densely placed hairs on the basal antennal segments so conspicuous in the male is lacking.

The holotype from the Guaynabo River, Puerto Rico, February 21, 1935; allotype and paratype from the Yúnez River, June 20, 1935.

Larvae and pupae collected at the same time and place resemble those of *Maruina californiensis* Kellog (1901). In the Cornell University Collection.

STUDIES OF THE ROOT SYSTEM OF COFFEA ARABICA L.

Part I.—Environmental Condition Affecting the Distribution of Coffee Roots in Coloso Clay

By J. Guiscafré-Arrillaga and Luis A. Gómez

Introduction

To the present, the aerial portion of plants have been more intensively and thoroughly studied in botanical and agronomic problems. The reasons for this are obvious, among the most important being that it is the part from which man usually derives more income and the easier on which to undertake investigations.

However, knowing that production in the tops of plants depend on the roots and particular environmental soil conditions it is clear that studies of the root system help a great deal the technologist and agronomist in the efficient performance of agricultural practices, such as systems and distances for planting, fertilizer application, general tillage operations, drainage and irrigation systems, control of diseases and erosion, intercropping and others of special application to particular crops, all of which contribute to a more productive aerial portion.

With these objectives in view and to obtain fundamental knowledge on which to base investigations and recommendations for necessary agricultural practices in the growing of coffee, this study was undertaken.

Literature Review

The distribution of roots of crop plants in the soil and related problems have been studied by Gómez (1), Lee (2), Lee and Bissinber (3), Nutman (4), (5), (6), Trench (7), Venkatraman (8), Weaver (9), Weaver and Christ (10). These investigators have devised and used various methods for the most accurate determination of the root system under study. Such methods may be classified as natural and artificial. Those methods in which specially designed boxes or cylinders are used for growing the plant the root system of which is to be studied, may be termed as artificial while the methods of excavating and weighing the roots of plants as they actually occur at different soil depths, or that of exposing and fol-

lowing the roots by washing with jets of water or loosening the soil with hand tools and drawing the root system to scale in the field, may be classified as natural.

The artificial method: This has been used by Lee (2) and Venkatraman (8). The method followed by Lee (1) consisted in planting gsuar cane seeds in boxes with detachable sides and poultry netting wire placed horizontally and filled up with soil at different depths. Once the plants had attained the desirable size, the soil was washed away and the roots exposed but held in their correct position by the horizontally placed poultry netting. In this way the distribution of the roots at different depths was determined. Lee (2) originated a more natural and accurate method later.

Venkatraman (8) used earthenware cylinders in which cane seeds were planted for studying the root distribution.

Natural methods: The following investigators have used the "natural methods" for the study of root systems of plants: Lee (2), (3), Gómez (1), Nutman (4), (5), (6), Trench (7) and Weaver et al. (9), (10).

The method used by Lee (2), Lee and Bissinger (3), while making studies of the root distribution of sugar cane in Hawaii and the Philippine Islands may be described as follows: after selecting 5 to 10 stools as uniform as possible in a commercial field, the cane is cut and the green and dry weights of the tops determined. Stakes are set exactly half way between the rows of cane to be studied and the contiguous rows on both sides. A cord is stretched around the four stakes enclosing the cane stools under study. Then the excavation is begun within this area and all soil removed to a depth of 8 inches care being taken that the excavation does not exceed 8 inches in depth. As the earth is removed from the area studied, it is thrown in a wire screen of ¼-inch mesh placed at one side of the excavation. The screen separates the roots from the soil. All the roots found in the top-most 8-inch layer represent the mass of roots of the 5 or 10 stools in the top-most 8 inches of soil. The roots from the top-most 8-inch layer are then collected in bags, labelled and held until the complete excavation has been made. Deeper excavations are then started and the roots separated for every 8-inch layer until the desired depth is attained, which is usually that point where the quantity of roots found is negligible. The roots from the various soil levels are then washed, separately air-dried, and oven dried, until all moisture is removed and weighed.

Following this method which is very accurate, the distribution of roots at various soil depths is determined with certainty. Lee (2), (3), prefers this quantitative method to the expensive, and almost impossible task of longitudinal measurements since the weights of roots may possibly be even better index of the absorbing surfaces.

Gómez (1) followed Lee's method for the study of the distribution of sugar-cane roots in certain soil types of Puerto Rico.

Nutman (4), (5), (6) has studied the root system of coffee, *Coffee arabica* L., in various soil types of British East Africa using various methods.

Where water was readily available Nutman studied the root system of coffee by washing the soil with fine jets of water under pressure. The soil was washed in layers and the roots exposed and followed to their terminations. The roots were pegged in their position on the soil face by means of long, pointed steel rods. When the roots of the whole selected sector were washed out, and the roots pegged in their natural positions a string grid of 1 ft. mesh was then erected and the root system drawn to scale in the field. Where water was not available, excavation was performed by hand with the help of hammers and chisels.

But Nutman (6) used furthermore the following method which he claims to be more accurate. This consists in digging a trench with one face 8 to 9 inches from the trunk of each experimental tree. The soil is then washed away in adequately measured 1 ft. cubes by a jet of water of ½ inch diameter and 10 pounds of pressure. The soil washed is examined and all roots from each cube are collected, washed, labelled and preserved. Then all the feeding roots are measured from a selected section of the root system. In this way it is determined by trees the distribution of the feeding area at various soil depths.

In addition Nutman (5) has studied the effect on the coffee root system of various soil conditions, such as presence of hardpans, aeration, height of the water table, soil reaction, manurial treatments and cultivation methods.

Trench (7) after studying the root system of coffee trees in Kenya carefully removed by washing, comments that the root system of coffee can be materially affected by environmental factors and that it can be modified by wise guidance and suitable treatments for proper development.

In the United States of America, Weaver and his associate (9), (10) have studied intensively the root systems of numerous plants

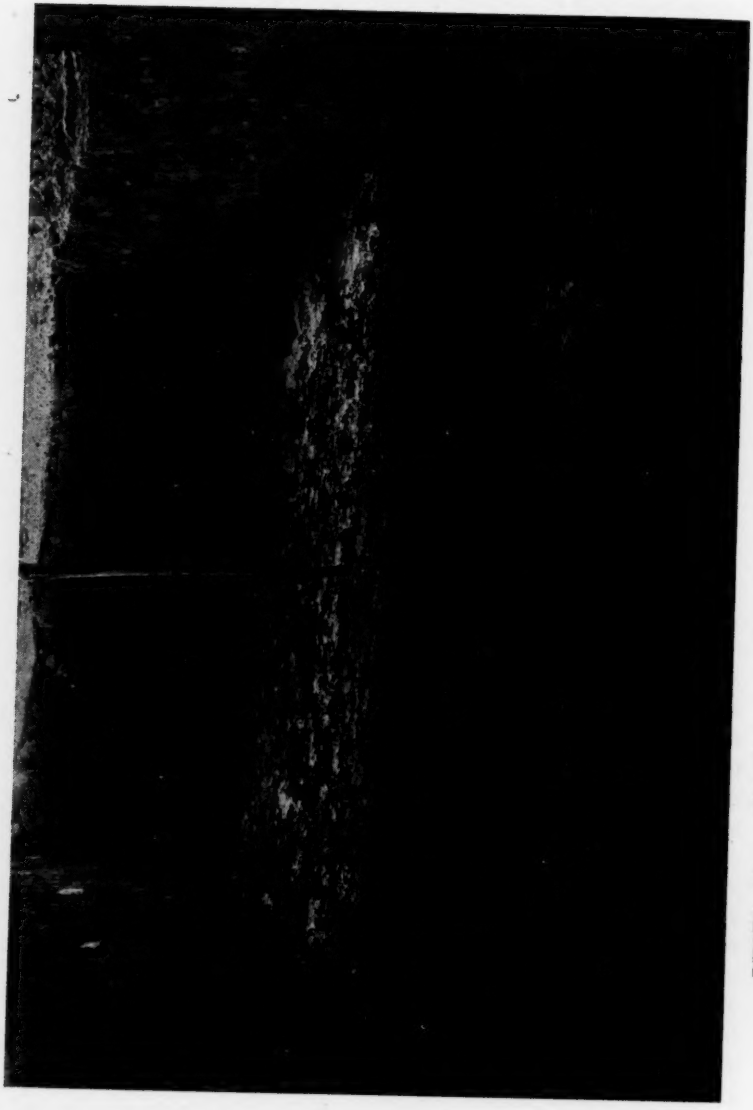


PHOTO. No. 1. Method of excavation; every block represents one cubic foot of soil.

in various regions of that country. His method consists in working into the side of a trench with hand tools and folowing up the roots by breaking away the soil. Once exposed, the entire root system is drawn to scale in the field.

After a critical study of the work done and the results accomplished by the investigators just mentioned, the writers developed a new method which is really an outgrowth of the methods developed by Lee (2), (3), Gómez (1) and Nutman (6) but which is thought to be more adaptable for the study of the root system of coffee in our prevailing soil and climatic conditions.

Before going into the details of the method used in this preliminary study, an account will be given of the conditions of the trees studied and their environment.

Conditions Relative to the Soil and Coffee Trees Studied on a Representative Soil Type of Puerto Rico

The six coffee trees selected for this study were located at the farm of the College of Agriculture and Mechanic Arts at Mayagüez, P. R.

These trees were growing in a 2-acre terrace of soil belonging to the Coloso Clay type and surrounded on two sides by a small stream and hills of low elevation of Catalina Clay. The Coloso Clay found in this terrace originated from alluvial and colluvial deposition of the stream and the neighboring hills. Terraces of this nature and soil type are quite abundant in the coffee region of the island. The drainage of this soil is poor during the rainy season due to the high level of the water table. This soil has been found to be quite productive when proper drainage systems are made. The physical and chemical analyses of this type of soil are shown in tables III and IV. The average annual rainfall for this region is 81 inches.

The six coffee trees used for this study were 7 years old. The average size of these trees was 299.16 cms. high, 159.66 cms. wide and of a trunk diameter of 3.70 cms. The individual sizes of all trees is shown in table VIII. The general vegetable conditions of the trees is shown by tree No. 6 in plate 3. All the trees studied belong to the arabian coffee type, *Coffea arabica* L., which is the coffee variety extensively planted in the island.

The general conditions of the field where the excavation was performed may be described as follows: The coffee trees were planted systematically in rows at 8 ft. $\times$ 8 ft. under leguminous shade trees

of "guaba", *Inga Inga* (L.) Britton, and "guamá", *Inga laurina* (Sw.) Willd., planted at an approximate distance of 16 ft. × 16 ft. The agricultural operations effected rearly consisted in weeding with a "machete" two or three times, and pruning the shade lightly after picking the crop. No fertilizer was ever applied to the trees in this field.

The excavations of the root system were started on February of 1937 and finished on May of the same year. The trees were in bloom when the tops were cut off.

Method of Procedure

For this study, six contiguous trees were selected in one of the innermost rows of the field. The tops were cut close to the soil surface and the green weights of the stems, leaves and lateral branches were obtained by direct weighing in the field. The dry weights of these same parts were obtained later after drying in the sun and in electric ovens. Table VIII shows the green and dry weights of each tree.

Once the tops were removed, stakes were placed halfway between the row of coffee trees to be studied and the neighboring rows on both sides. A cord was stretched around these stakes thus marking a total area of 384 sq. ft. equivalent to an area of 64 sq. ft. corresponding to each of the six trees. The position of the stakes, the top-most total area excavated and the planting distance of the trees is shown in text figure No. 1.

The area corresponding to each tree was then divided in squares of one sq. ft. each by means of 5-inch nails and cords. The excavation was begun, and the soil was removed in blocks of exactly one cubic foot in the 64 sq. ft. area corresponding to each tree. The depth of excavation was carefully checked with a 12-inch hand ruler. The roots found in each cubic foot excavated per tree and per layer were separated from the soil by a wire screen of ¼ inch mesh and by hand. The roots found were collected in cloth bags and taken to the laboratory where they were washed and spreaded under shade until the excess of water was evaporated. Then the green weights were determined. Afterwards the roots found in each cubic foot were dried in electric ovens to determine the dry weights. The same was done with a second layer to a depth of 24 inches, with a third layer to a depth of 36 inches, and to a fourth layer to a depth of 48 inches, in which layer the amount of roots found was very small. Details

concerning the excavation and separation of the roots from the soil are shown by plates Nos. 1 and 2.

The excavation by cubic foot was controlled by an excavation map specially prepared for the total area to be excavated for each tree, by numbering each block. The excavation map of the root system of the six trees used for the four layers excavated by blocks of one cubic foot each is shown in text figures Nos. 3, 4, 5, 6, 7 and 8.

It was possible to make the excavations by blocks of one cubic foot due to the stiffness of the clay contained in the soil. It is realized that in loose soils this method is impracticable, but it is claimed to be the most accurate method for the study of root systems in clay soils because it makes possible to determine not only the quantities of roots at different soil depths but also the distribution of the roots in definite lateral areas. In other words, this method determines the lateral spread as well as the vertical penetration of the roots studied.

It is expected that some of the roots of the trees under study have extended on both sides beyond the excavations limits, but in a field planted at uniform distances, the loss of roots beyond the limits of the excavation are compensated by the roots of the trees of the neighboring rows which extend into the excavation. This idea advanced by Lee (2), (3) is applicable to systematic root studies in fields planted out at uniform distances; the types of field that should be used in studies of this nature.

The two major handicaps in the execution of this study were, the search for a systematic plantation, which are still few in the island and the separation of the coffee roots from the roots of neighboring shade rtees, as all coffee is grown under shade in Puerto Rico. This separation was possible by a thorough study, previous to the excavation of the rot systems under study, of the roots of coffee, and the shade trees in the vicinity. The morphology, color and odor of the coffee roots is typical, but in order to avoid any errors, as the separation of the roots from the soil was done by laborers, the roots found in each cubic foot excavated were thoroughly inspected by the writers and the roots of the shade trees discarded.

The writers also admit that the green weights of the roots are not completely accurate. There is the possibility for some water to be lost, thru the necessary handling during the excavation, separation and weighing, but if care is taken to perform under shade all the operations involved in the excavation, separation, washing and drying until the excess of water brought in by the washing is re-

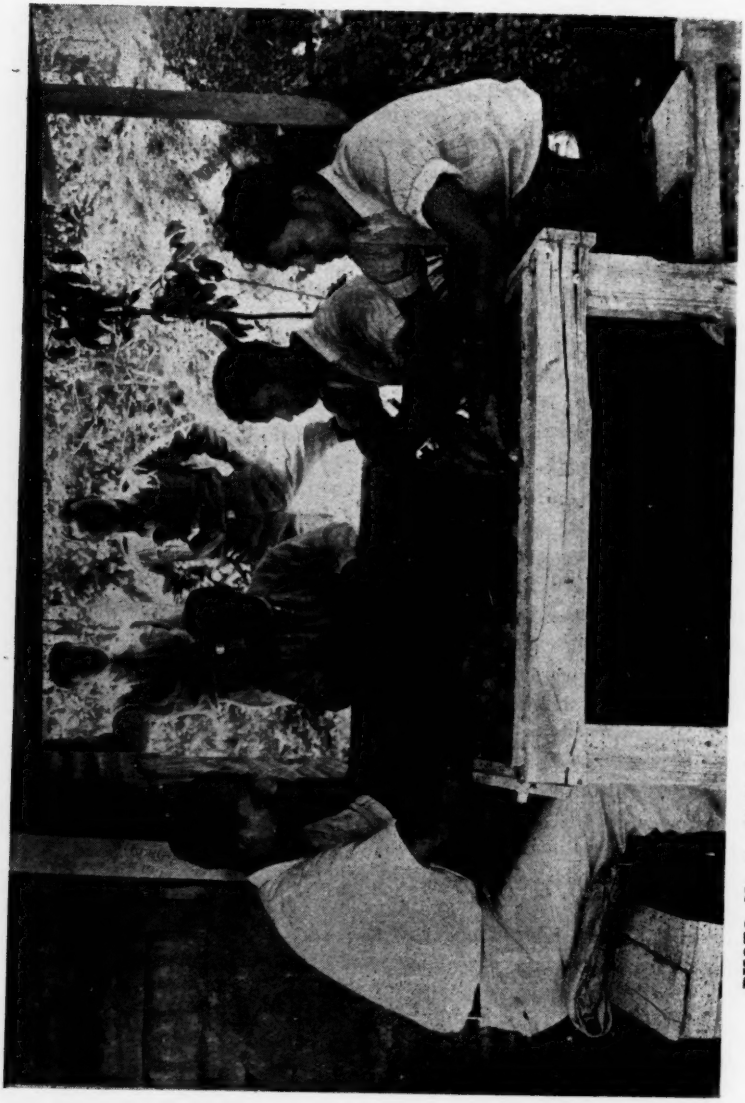


PHOTO. No. 2. Method of screening roots as the different blocks of soil were excavated.

moved, it most be realized that there is accuracy in the method used for the determination of the green weights. Although before starting the study, the difficulty involved in the determination of the green weights of the roots was appreciated these were obtained in order to compare the ratios of tops to roots based on the green and dry weights of both parts of the trees.

Results

NINETY-FOUR PERCENT OF THE COFFEE ROOTS WERE FOUND IN THE TOP-MOST 12 INCHES OF SOIL:

That 94 percent of the roots were present in the top-most 12 inches of soil is shown by the following tables I and II in which the greatest quantity of roots of each of the six trees was found in the top-most 12 inches of soil.

The quantity of roots decreases tremendously from the 12-inch level downward to the depth of 48 inches at which the quantity of roots found was negligible. A small amount of roots was found for trees Nos. 3 and 6 at a depth of 48 inches. According to the figures, it is shown that 94 percent of all rots was found in the top-most 12 inches and that practically the whole root system of seven-year old coffee trees growing in Coloso Clay is found in the first 24 inches of soil, since 99 percent of all the roots of the six trees under study were excavated above the 24-inch level. (see Photos. 4 and 5.)

THE PERCENTAGE OF ORGANIC MATTER IS HIGH IN THE COLOSO CLAY TOP-SOILS:

There was 2 percent of organic matter in the top-most 12 inches of soil as indicated by table III. This is remarkably high for Puerto Rican soils. The quantity of organic matter decreases tremendously at lower depths. The high content of organic matter in the first layer is undoubtly due to the acumulation of leaves and other vegetable remains of the coffee, shade trees and weeds. The high content of organic matter may have a direct influence on the development of more roots at the surface, although the effect of better aeration of surface layers is also a factor to be considered.

As shown also by table III, the percentages of silt and clay was practically the same at all soil levels while the percentage of total sand was greater at the 36 and 48 inch level.

The high percentage of clay, and average of 72 percent, makes this a distinctly clay soil.

TABLE I

DISTRIBUTION BY WEIGHT OF ROOTS OF COFFEE TREES, 7 YEARS OLD, IN COLOSO CLAY SOIL AT DIFFERENT SOIL DEPTHS

Layers	Depth	Tree I	Tree II	Tree III	Tree IV	Tree V	Tree VI	Total weight of roots per layer
		Grams	Grams	Grams	Grams	Grams	Grams	Grams
1st	0''–12''	162.8570	288.5323	199.9569	114.2361	179.8376	229.7501	1175.18
2nd	12''–24''	4.3731	10.7888	11.3501	5.5535	16.0142	15.1872	63.26
3rd	24''–36''	0.1176	1.0372	0.2637	0.9622	0.9378	5.4049	8.72
4th	36''–48''	0.0000	0.0000	0.6521	0.0000	0.0000	0.0154	0.67
Totals	48''	167.3477	300.3583	212.2228	120.7518	196.7896	250.3576	1247.83

Underscored figures indicate highest concentrations of roots.

TABLE II

TOTAL DISTRIBUTION OF COFFEE ROOTS PER LAYER AT DIFFERENT SOIL DEPTHS

Depth of excavations by layers		Roots in each layer	
		Grams	Percent
1st layer	0''–12''	1175.18	94.17
2nd layer	12''–24''	63.26	5.07
3rd layer	24''–36''	8.72	0.70
4th layer	36''–48''	0.67	0.06
Total	48''	1247.83	99.99

TABLE II.

PHYSICAL ANALYSES OF SOIL AT DIFFERENT DEPTHS

Depths	Wet sieving method Percentages						Bouyoucos' method Percentages		
	Organic matter (1)	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand (2)	Total sands	Silt	Clay
0''-12''	2.00	0.25	0.53	1.60	4.30	2.12	8.80	16.80	74.40
12''-24''	0.80	0.16	0.18	0.25	0.87	5.34	6.80	18.40	74.80
24''-36''	0.50	2.20	1.80	1.70	3.50	8.00	17.20	14.40	68.40
36''-48''	0.58	1.70	1.60	1.60	4.20	4.50	13.60	18.80	67.60

(1) Determined by Schollenberger, La Motte method.

(2) Figures of very fine sand were obtained by subtracting sum of fine graved, coarsesand, Medium sand and fine said from total sands.

TABLE IV

CHEMICAL ANALYSES OF THE SOIL EXCAVATED AT DIFFERENT DEPTHS

NUTRIENT DISTRIBUTION BY LAYERS—PERCENTAGES OF SOIL WEIGHT

Layers depths	Soil reaction pH	Nitrogen N	Phosphoric acid P_2O_5	Potash K_2O	Lime CaO	Magnesia MgO	Silica SiO_2	Aluminum Al_2O_3	Iron Fe_2O_3	Manganese MnO	Percent moisture
0''-12''	4.60	1.490	0.100	1.400	0.53	0.955	68.440	12.775	7.230	0.080	24.92
12''-24''	4.65	0.905	0.035	1.625	0.52	0.700	69.415	14.830	5.655	0.065	22.26
24''-36''	4.60	0.670	0.105	1.615	0.44	0.655	65.980	8.885	15.115	0.100	22.88
36''-48''	4.77	0.680	0.115	1.750	0.40	0.635	63.785	7.435	18.420	0.105	21.67

Underscored figures indicate higher concentration of nutrients.

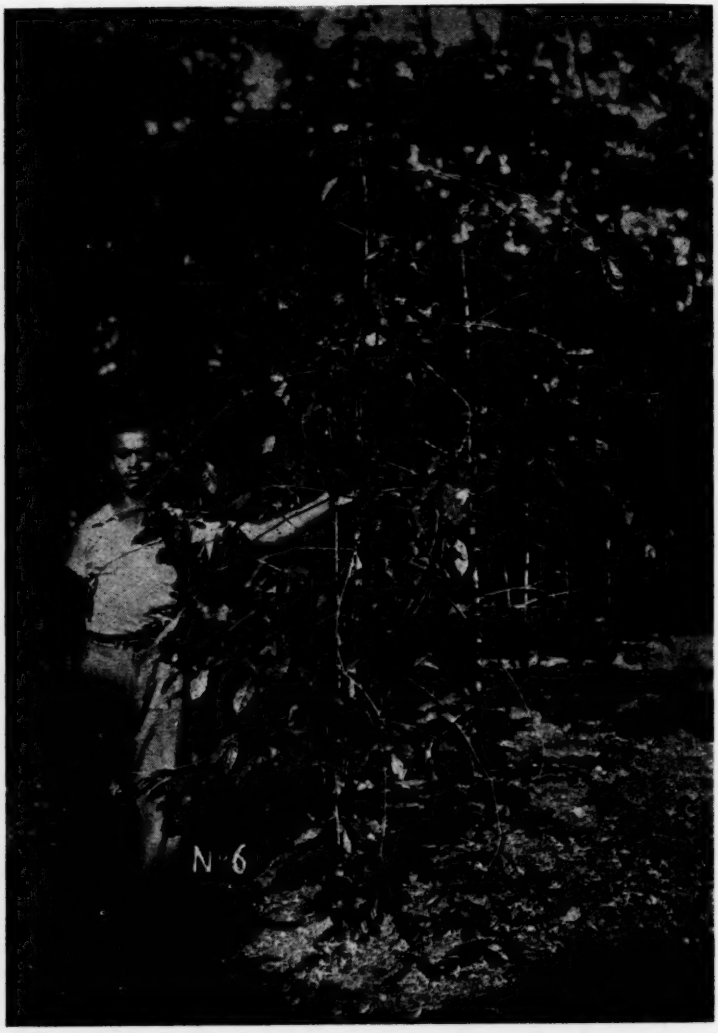


PHOTO No. 3. The size and vegetative conditions of one of the six trees studied.

THE PRINCIPAL PLANT NUTRIENTS ARE PRESENT IN FAVORABLE QUANTITIES AT THE SOIL LEVELS STUDIED:

Upon examination, table IV shows that the nitrogen and potash are present in rather high quantities, while phosphorus is present in low quantities. The quantity of these three nutrients is practically the same at all depths.

The pH, on the average 4.6, indicates that the soil reaction is decidely acid. The content of calcium was extremely low and as well as the pH, was practically the same for all soil levels. The iron was present in higher quantities at the 36 and 48-inch levels while alumninum was present in lower amounts at these same levels.

The percentage of moisture although higher at the first layer was practically the same at all the other soil levels studied.

Magnesia is present at all soil depths in greater quantities than calcium.

In general, according to the chemical analysis shown by table IV, the Coloso Clay is a good soil. It has proved to be productive for sugar cane growing specially in dry years and when using the "gran banco" system of planting which provides adequate conditions of drainage.

In text figure 2 the distribution of the coffee root system is shown in relation to the root weight and physical and chemical soil analyses of the different soil layers.

A HEAVY TOP IS NOT DEPENDENT ON A STRONG AND HEAVY ROOT SYSTEM:

In tables V and VI is shown the advantages of the new method used for this study.

In table V, in the first layer, of the 384 cu. ft. excavated for the six trees, only 242 cu. ft. were found with roots and the number of cubic feet found with roots decreased enormously in the other three layers. In the fourth layer, of 384 cu. ft. excavated, only 4 cu. ft. were found with roots and these belonged to the root systems of trees Nos. 3 and 6. Text figures 3 to 8 show the advantages still more clearly since in the excavation maps for each tree, the lateral extension and vertical penetration of the roots is indicated by the dry weights of the roots found in each cubic foot excavated. Upon examination, each individual excavation map shown in text figures 3 to 8, gives an aproximate idea of the form of the root

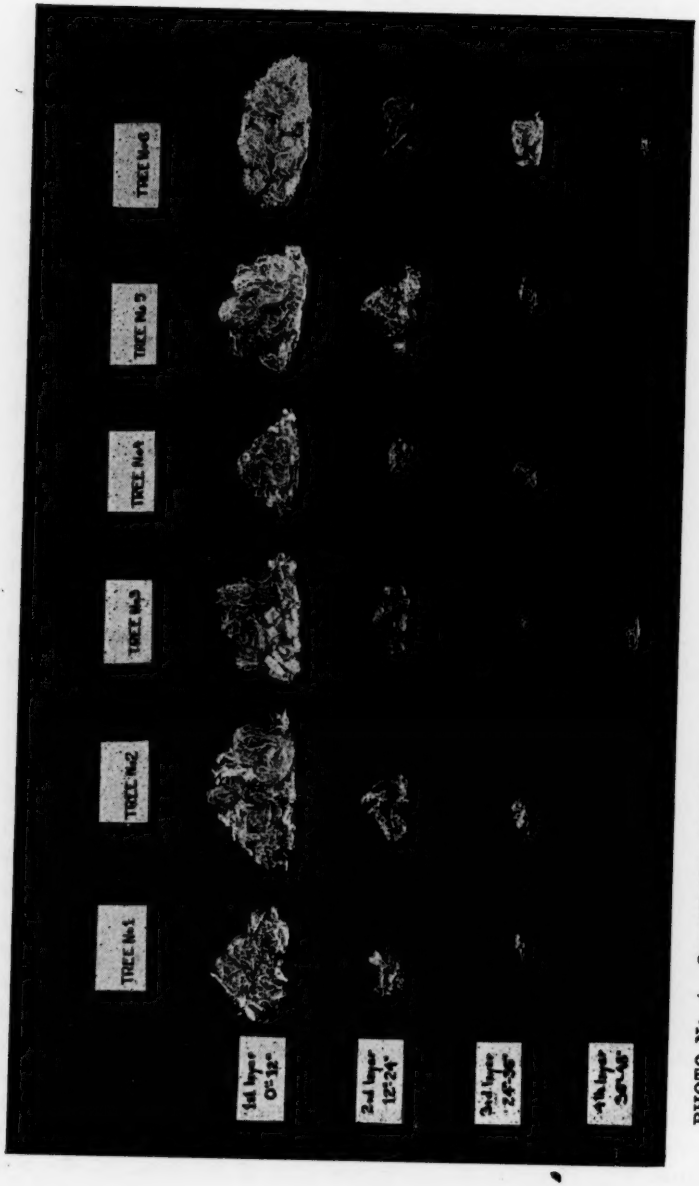


PHOTO No. 4. Quantitative distribution of roots found per tree and per layer in the six coffee trees studied.

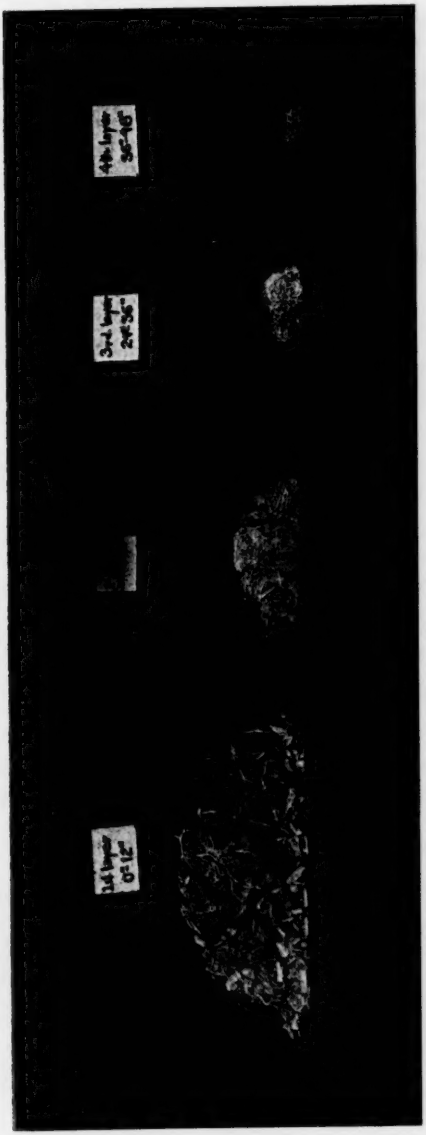


PHOTO No. 5. Total amount of roots found in the different layers of the six coffee trees in this study.

system of each 7-year-old coffee tree in this type of soil. According to the dry weight of roots found per cubic foot per tree and to the position of the blocks of soil found with roots, the form of the root system is that of an inverted cone of rather short height. It is also shown in text figures 2 to 8 that the vertical penetration of the root system is 4 feet and the lateral extension is approximately 4 feet also.

TABLE V

DISTRIBUTION OF ROOTS AT DIFFERENT SOIL DEPTHS IN RELATION TO TOTAL VOLUME OF SOIL EXCAVATED AND TO VOLUME OF SOIL WHERE ROOTS WERE PRESENT

QUANTITIES OF ROOTS, DRY WEIGHTS

Layer depths	Total weight of roots per layer of six coffee trees	Total cubic feet excavated per layer	Weight of roots per layer per cubic foot	Cubic feet excavated where roots were found	Weight of root per cubic foot where roots were found
	Grams		Grams		Grams
0″–12″	1175.18	384	3.060	242	4.86
12″–24″	63.26	384	0.140	103	0.61
24″–36″	8.72	384	0.020	35	0.32
36″–48″	0.67	384	0.002	4	0.17
Total	1247.83	1536		384	

In table VI, is shown that of a total of 256 cu. ft. excavated for each of the six trees studied, the number of one cubic foot blocks containing roots fluctuate between 51 and 76 blocks.

The trees with the heaviest root systems, Nos. 2 and 6, do not have the most extensive root systems since all their roots were found in 65 and 57 one-cu. ft blocks respectively. If table 8 shown later is examined, it will be noticed that trees Nos. 2 and 6 do not possess the heaviest tops.

TABLE VI

WEIGHT OF ROOTS PER CUBIC FOOT OF SOIL PER TREE

Tree number	Dry weight of roots per tree	Total cubic feet excavated per tree	Weight of roots per cubic foot	Cubic feet where roots were found	Weight of roots per cubic foot where roots occurred
	Grams		Grams		Grams
1	167.35	256	0.65	62	2.70
2	300.36	256	1.17	65	4.62
3	212.22	256	0.82	73	2.90
4	120.75	256	0.47	51	2.37
5	196.79	256	0.77	76	2.59
6	250.36	256	0.98	57	4.39

With the exception of tree No 4 the figures for the dry weights of tops and roots and number and position of the one-cubic foot blocks excavated for each tree found with roots, indicate that a heavy top growth is not dependent on a heavy and extensive root system. This is in accord with Lee's (2), (3) and Gómez (1) investigations on the root systems of sugar cane in Hawaii, the Philippine Islands and Puerto Rico.

THERE IS NO FIXED RATIO OF TOPS TO ROOTS IN COFFEE TREES:

Studying the figures for green and dry weights of tops to roots ratio since it is different for all the six trees studied. Based on the total dry weights of the tops and roots of all trees, the ratio of tops to roots ratio is 7. Inasmuch as these figures are practically equivalent it may be stated that the ratio of tops to roots is aproximately 8, taking in consideration either the dry or green weights of both parts of 7-year-old coffee trees.

In table VII information is given also regarding fertilizer applications and moisture conditions of the six trees studied.

THE TRUNK DIAMETER OF COFFEE TREES IS A GOOD INDICATION OF A HEAVY TOP AND A STRONG ROOT SYSTEM:

In order to understand clearly the possible interrelationships between certain botanical characteristics of the tops and roots of the trees studied, table VIII was prepared.

This table shows the following:

(*a*) That the average tree size for the trees used in this study has a height of 299.16 cms., almost 10 ft.; 159.66 cms. or 5 ft. 4 in. of lateral spread and a trunk diameter of 3.70 cms., approximately 1½ in.

(*b*) That the average tree top and root system in this series weighed 1849.16 grs. and 207.97 grs. (dry weight) respectively.

(*c*) That the trunk diameter of coffee trees was more indicative of a heavy top and a strong, extensive, root system than either the height or lateral spread. The figures in table VIII show this clearly; the trees with a trunk diameter of 4 cms. or above are in general the trees having the heaviest and most extensive root systems. For comparing the root extensiveness of the six trees, refer to table VI.

TABLE VII

RATIO OF TOPS TO ROOTS OF EACH TREE BASED ON GREEN AND DRY WEIGHTS AND ITS RELATION TO MOISTURE AND FERTILIZER

DRY WEIGHTS

Tree number	Fertilizer applied	Average percent of soil moisture for all layers	Tops	Roots	Ratio of tops to roots
			Grams	Grams	
1	None	22.93	1,642.00	167.35	9.81
2	None	22.93	2,038.00	300.36	6.78
3	None	22.93	1,925.00	212.22	9.07
4	None	22.93	1,471.00	120.75	12.18
5	None	22.93	2,094.00	196.79	10.64
6	None	22.93	1,925.00	250.36	7.68
Totals			11,095.00	1,247.83	8.88

GREEN WEIGHTS

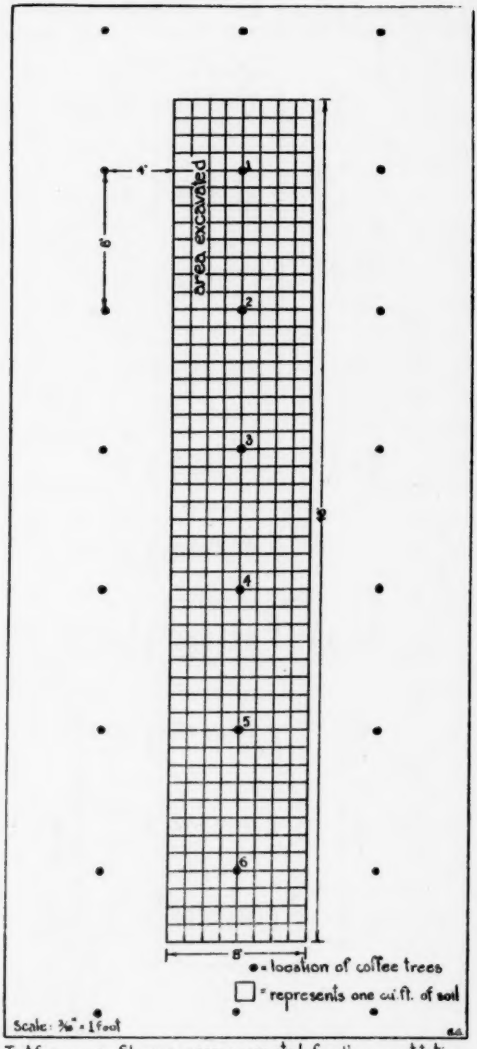
1	None	22.93	2,500.00	338.09	7.39
2	None	22.93	3,500.00	591.81	5.91
3	None	22.93	3,100.00	404.08	7.67
4	None	22.93	2,050.00	263.98	7.76
5	None	22.93	3,400.00	396.95	8.57
6	None	22.93	3,100.00	526.28	5.89
Totals			17,650.00	2,521.19	7.00

TABLE VIII

SIZE, GREEN AND DRY WEIGHTS OF THE TREES STUDIED

Tree number	Height	Lateral spread	Trunk diameter	Uprights (1)		Laterals (2) and leaves		Tree tops (3)		Roots	
				Green weight	Dry weight	Green weight	Dry weight	Green weight	Dry weight	Green weight	Dry weight
	Cms.	Cms.	Cms.	Grams	Grams	Grams	Grams	Grams	Grams	Grams	Grams
1	282	160	3.00	1200	538	1300	1104	2500	1642	338.09	167.35
2	354	194	4.00	1800	821	1700	1217	3500	2038	591.81	300.36
3	306	160	4.00	1500	708	1600	1217	3100	1925	404.08	212.22
4	242	116	3.00	1050	481	1000	990	2050	1471	263.98	120.75
5	364	124	4.50	1550	764	1850	1330	3400	2094	396.95	196.79
6	247	204	4.00	1300	708	1800	1217	3100	1925	526.28	250.36
Totals	1795	958	22.50	8400	4020	9250	7075	17650	11095	2521.19	1247.83
Averages	299.16	159.66	3.70	1400	670.00	1541.66	1179.16	2941.16	1849.16	420.19	207.97

Uprights (1) Vertical stems.
Laterals (2) Horizontal branches or fruit-bearing branches.
Tree tops (3) Uprights, laterals and leaves.



Text figure no 1: Shows area excavated for the quantitative determination and distribution of the root system of *Coffea arabica, L.*

Physical analysis of soil Per cent				Quantities of roots Dry weight in grams	
Sand	Silt	Clay	Organic matter	Total weight per layer	Per cu. ft per layer
8.80	16.80	74.40	2.00	1175.18	3.06
6.80	18.40	74.80	0.80	63.26	0.14
17.20	14.40	68.40	0.50	8.72	0.02
13.60	18.80	67.60	0.58	0.67	0.002

Text figure 2.

Diagram showing distribution of coffee roots correlated with roo

Average green weight of tops (laterals, leaves and uprights) ..... 1849.16 grams.
" " " " laterals and leaves ..... 1179.16 "
" " " " uprights ..... 670.00 "
" lateral spread of trees ..... 159.66 cms.
" height of trees ..... 299.16 cms.
" trunk diameter of trees ..... 3.75 cms.
(averages determined on the basis of 6 trees studied)
Volume of excavation per tree ..... .256 cu. ft.
Volume excavated for all trees ..... .1536 cu. ft.

NUTRIENT DISTRIBUTION
(Percentages of soil weight)

Soil reaction pH	Nitrogen N	Phosphoric acid-P_2O_5	Potash K_2O	Lime CaO	Magnesia MgO	Silica SiO_2	Aluminum Al_2O_3	Iron Fe_2O_3	Manganese MnO	Percent moisture
4.60	1.49	0.10	1.40	0.33	0.95	68.44	12.77	7.23	0.08	24.92
4.65	0.90	0.03	1.62	0.32	0.70	69.41	14.83	5.65	0.06	22.26
4.60	0.67	0.10	1.61	0.44	0.65	65.98	8.88	15.11	0.10	22.88
4.77	0.68	0.11	1.75	0.40	0.63	63.78	7.43	18.42	0.10	21.67

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d with root weights and physical and chemical soil analyses.

Other information that can be obtained from table VIII is in relation to the water contents of uprights, lateral and leaves and roots. Based on the dry and green weights, there is approximately 50 percent of water in the uprights; 23 percent in the lateral branches and leaves, 39 percent in the whole tree tops and 50 percent in the roots. The figures definitely indicated the woodiness of the coffee tree.

Discussion and Conclusions

Recognizing the necessity of fundamental knowledge regarding the root system of coffee in Puerto Rico in order to be able to introduce better agronomic methods for growing this crop and to be able to offer definite explanations for failures attained, the present study was undertaken. A new method was used endeavoring to obtain abundant as well as accurate and reliable information. This method, consists in excavating one-cubic foot-blocks of soil in definite volumes of soils corresponding to each of the trees under investigation. The green and dry weights of the roots found in each cubic foot of soil is obtained and by using an excavation map for each of the root systems, the weight as well as the vertical and horizontal distribution of the roots excavated for each tree is obtained. The method used, just mentioned is the outgrowth of methods previously used by Lee (2, (3), Nutman (6) and Gómez (1) for studying the root systems of sugar cane and coffee.

Lee (2), (3) trying to get a quantitative distribution of the roots of sugar cane at different soil levels designed and successfully executed an accurate, fast, practicable and relatively inexpensive method of studying root systems of plants which has been fully described. Using Lee's method, no roots are lost since these are carefully separated by screens and by hand as the soils is excavated by 8-inches layers at several depths. By weighing the roots excavated by layers, an accurate distribution of the roots of the plant studied at definite soil depths is obtained. However, no information is obtained as to the lateral extension of the roots. Lee's method has the further advantage that it is practicable under conditions naturally existing in commercial fields.

Gómez (1) followed Lee's method for studying the root system of sugar cane in the western part of Puerto Rico and obtained useful and practical information.

Weaver and his associates (9), (10) studied intensively the root systems of many different plants in the United States by working into the side of a trench with hand tools and following up the roots

by breaking away the soil. Once the root system is exposed, it is drawn to scale in the field.

Although Weaver's method gives information as to the vertical penetration and lateral extension of the root systems, it must be recognized that a certain quantity of small roots must be lost necessarily in stiff soil since a soil of this nature breaks out in lumps of various sizes. The loss of these small roots will affect the results obtained because no accurate information can be obtained regarding the location of the real absorbing area of the root system. Besides, the information obtained in relation to the lateral extension of the roots is not representative because the roots do not probably extend to the same distances in all directions, taking as axis the trunk of the tree and its prolongation, the central root. In other words Weaver's method gives good information if the vertical penetration and lateral extension of the principal roots of the entire root system is desired, but since a certain quantity of the roots is lost, is impossible to get the real location of the absorbing surfaces at different soil levels.

Nutman (6) has used two methods for the study of the root system of coffee in Kenya. The first is very similar to that developed by Weaver and his associates (9), (10). The second method, which according to Nutman is possibly the most accurate method for studying the root system of plants consists, briefly, in washing away the soil in 1 foot cubes with fine jets of water at a definite selected section of the root system. The roots found at each cube are washed and the total length of the feeding roots measured.

The disadvantages of this method are obvious. In computing the total feeding area for the entire root system, it must be assumed that the average diameter and concentration of the root hairs is constant, a great percentage of the total roots is ignored since only a section of the entire root system is studied and the longitudinal measurement of the feeding roots must be necessarily a complicated and expensive procedure. Nutman developed this method believing that the longitudinal measurement of the feeding roots is the best indication of the absorbing area of the tree. But that the quantitative determination by weighing the roots is as good an indication of the absorbing capacity of the root system as longitudinal measurements, was first advanced and proved by Lee (2), (3) and later corroborated by Gómez (1) and the writers. Besides, although Nutman insists on longitudinal measurements, the figure obtained with his method (6) indicate that the greatest concentration if feeding roots

occur in the top-most 12 inches of soil which definitely establishes the fact that the weight of roots at definite levels is an accurate means of determining the location of the absorbing area of the root system. This is to be expected since the concentration of large numbers of feeding roots although of small size and weight will affect the total weight of the roots found at a definite soil depth.

Nutman's (4), (5), (6) intensive works on the root system of coffee in various types of soil in Kenya, have undoubtly contributed to explain and solve important problems related with the coffee industry of that country.

Nutman (5) also studied the effects of various soil conditions in modifying the root-growth of coffee trees and found that in general, hard-pan has little effect on root development; lava, mud-stone gravel strata and high water-table cause penetration to be inhibited in greater or less degree and that the acid limit of satisfactory growth is at a pH of 5.8 to 6.00.

According to the results obtained in this study 94 percent of coffee roots of 7-year-old trees in Coloso Clay are found in the top-most 12 inches of soil. These results generally agree with Nutman's results in Kenya (6) by which he found the greatest concentration of roots in the top-most 12 inches of soil, with Lee's (2) results in which he found that sugar cane either hilled-up or in furrows, more than 85 percent of the roots were found in the top-most 24 inches of soil and with Gómez (1) results in Puerto Rico in which 51.39 percent of the total amount of roots excavated at a depth of from 0 to 48 inches, is found in the hilled-up and top-most 0–8 inch soil depth.

However, it is believed by the writers that the concentration of 94 percent of the total amount of roots excavated is a little abnormal and that must be due to an abnormal soil condition, in this case, the imperfect drainage typical of the Coloso Clay soil. From measurements taken on individual 2-year old trees in the coffee experimental fields planted at the Puerto Rico Experiment Station of the United States Department of Agriculture at Mayagüez which indicate the height, lateral spread and trunk diameter that may be attained by trees under proper soil and cultivation, and from observations made on individual trees at commercial fields, it is found when comparing the growth of trees used for this study with trees of less age, that the 6 trees studied had not developed properly.

The Coloso Clay Soil being regarded as a productive soil in Puerto Rico is not responsible for the growth attained by the trees in 7 years, but the improper drainage due to special environmental con-

ditions prevailing in the locality where the excavations were performed. It is expected that with better drainage conditions the growth attained by the six trees would had been greater and the penetration and lateral extension of the root system would had been greater also at the various soil depths studied.

Although Coloso Clay is not the most common type of soil found in the coffee region of Puerto Rico it is present at flat, level places, near streams in farms where the Catalina Clay is abundant. Therefore, it is recomemnded to provide the coffee plantations growing in localities of conditions similar to those prevailing at the place where these studies were conducted, with proper drainage so that the growth of the trees may be normal and the production of the field, greater.

The relatively high percent of organic matter of Coloso Clay accounts to some extent for the greater concentration of roots at the top-most 12 inches of soil although the effect of better aeration of surface layers is also responsible for a greater quantity of roots to be present in the first layer excavated. Nutman (5) found that manurial aplications always resulted in an increased feeder-growth in the neighborhood of the manure.

Apparently, the texture of the soil and the concentration of the principal plant foods do not affect the growth of roots. This applies especially to the results obtained by this study because with the exception of a few figures of the physical and chemical analyses of the 4 soil depths studied, the texture and the concentration of nutrients was quite uniform for the 4 layers in which roots were excavated.

Contrary to the common believe that an exhuberant vegetative condition of tree tops must be correlated with a heavy and extensive root system, the results obtained in this study indicate that the conditions of growth of tree tops cannot be considered in figuring the conditions of growth of the root system because a heavy top is not dependent on a strong and extensive root system, judging from the figures shown in tables V, VI and VIII. The results obtained are in accord with those obtained by Lee (2), (3) and Gómez (1) in their stuides of the root systems of sugar cane in Hawaii, the Philippine Islands and Puerto Rico.

According to the figures shown by table VII there is no fixed ratio of tops to roots in coffee no matter whether dry or green weights of tops and roots are used for determining the ratio. This accords with Weaver's (9), (10) results with studies of the root systems of plants in the United States. It may be stated conclusively that the ratio of tops to roots of young coffee trees was approximately 8:1.

In selecting trees with a vigorous and abundant vegetative condition at the tops and strong, extensive root systems, the diameter of the trunk is a better indication of the possession of these desirable characteristics than either the lateral spread or the height. This was shown definitely by the figures in tables VI and VIII already explained. In the six trees studied, those with a trunk diameter of 4 cms. or above were the trees with the heavier tops and heavier and more extensive root systems.

The new method of studying root systems of crop plants, developed by the writers and used for studying the root system of coffee, *C. arabica* L. in Puerto Rico, besides making it possible to obtain the information discussed already, enables us to propose a description for the root system of coffee based strictly on the results obtained. Such root system may be described to have the form of an inverted cone with a wide base; the spread of the roots in the top-most 12 inches of soil, and a rather small height, the vertical penetration. There is really no pivot or main root in the coffee root system. The broad, central root noticed in text figure No. 2, is part of the stem, buried as a result of a tendency of our farmers to plant the coffee seedlings too deep into the planting holes. At a very short distance from the collar of the stems (the collar is regarded as that point in between the stem and the root system) a number of roots are found spreading out laterally and vertically which have a greater diameter than any other roots in the system. These main or primary roots give rise to secondary and tertiary roots, each of smaller diameter, and largely on the tertiary roots the root hairs are originated. According to the results obtained and the observations made in the field, the tertiary roots with root hairs are present in great quantities in the top-most 12 inches of soil and they originate at any point or distance from the center of the root system. The tertiary roots with the root hairs may originate at any part of either the main or secondary roots. It must be explained that the terminology of main, secondary and tertiary is based on the diameter of the roots and not on a systematic branching, in other words, tertiaries with root hairs have been observed to occur even on the buried stem adjoining the root system.

From the description of the root system just proposed it may be concluded that the absorbing area of the root system of coffee is not confined to definite places on the soil, but is evenly distributed in all places penetrated by the main and secondary roots.

Application of the Results Obtained

Athough the results obtained thus far need further confirmation, with the information gathered, it is possible to make some recommendations for the improvement of agricultural operations followed in the coffee plantations as follows:

(*a*) The greatest quantity of roots, 94 percent of the total roots excavated for the six trees, is found in the top-most 12 inches of soil.

(*b*) In the top-most 12 inches of soil, the roots of some of the trees extended laterally more than four feet.

(*c*) The maximum vertical penetration of the roots of most trees is three feet.

(*d*) The high content of the organic matter of the excavated at the top-most 12 inches and the better aeration of surface layers are apparently responsible for the greater quantities of roots found in the top-most 12 inches of soil.

In view of these facts, the young coffee tree is a surface feeder and shade trees or crop plants such as oranges and bananas should never be interplanted with coffee because of similar root-habits. In case, bananas are used to provide shade to the young coffee seedlings, the banana plants should be eliminated as soon as the permanent shade trees provide the coffee with the desired shade. Also, the excessive number of shade trees per cuerda, usually noticed in the plantations should be eliminated in order to reduce the competition for plant food to a minimum.

Coffee seedlings should always be planted at a minimum distance of 8 ft. $\times$ 8 ft. This is shown clearly in the first layers of the excavation maps (text figures 3 to 8) of most trees. The roots in the top-most 12 inches extended laterally 4 ft. or more showing that young trees in a relatively small number of years need and individual area of 64 sq. ft. for the development of the roots. When it is supposed that older trees will develop stronger and more extensive root systems it is realized that the minimum planting distance must be at 8 $\times$ 8 ft. Therefore, a cuerda of coffee should not have more than 625 coffee trees in order to provide an adequate land surface from which to withdraw an ample supply of plant foods.

The surface-feeding habit of coffee trees specially while young requires deep soils for a reasonable amount of growth and productivity. Many failures to grow coffee on shallow soils have been recorded.

Tree no. 1

First layer: 0"-12"

B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
O	O	O	0.1111	0.1051	0.0907	0.0274	0.0119
B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16
0.0614	0.0550	0.1762	0.1680	0.4464	0.1740	O	O
B-17	B-18	B-19	B-20	B-21	B-22	B-23	B-24
O	0.5104	2.8452	3.1360	3.4534	1.3130	0.0708	O
B-25	B-26	B-27	B-28	B-29	B-30	B-31	B-32
0.0074	0.6196	3.2126	50.3152	58.1018	2.6816	0.4864	O
B-33	B-34	B-35	B-36	B-37	B-38	B-39	B-40
O	0.3112	0.1170	4.5854	18.4422	1.1174	0.3558	O
B-41	B-42	B-43	B-44	B-45	B-46	B-47	B-48
O	0.2136	0.2164	0.3418	4.4640	1.8186	0.2718	O
B-49	B-50	B-51	B-52	B-53	B-54	B-55	B-56
O	O	O	0.1200	0.3690	0.5060	O	0.0312
B-57	B-58	B-59	B-60	B-61	B-62	B-63	B-64
O	O	O	O	O	O	O	O

Second layer: 12"-24"

B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
O	O	O	O	O	O	O	O
B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16
O	O	0.3414	0.0206	O	O	O	O
B-17	B-18	B-19	B-20	B-21	B-22	B-23	B-24
O	0.0618	0.1518	0.4618	0.2472	O	O	O
B-25	B-26	B-27	B-28	B-29	B-30	B-31	B-32
O	O	0.0684	0.7162	0.4862	O	O	O
B-33	B-34	B-35	B-36	B-37	B-38	B-39	B-40
O	O	O	0.6818	0.1612	0.0416	0.0117	O
B-41	B-42	B-43	B-44	B-45	B-46	B-47	B-48
O	O	O	0.0868	0.1680	0.4412	0.0532	O
B-49	B-50	B-51	B-52	B-53	B-54	B-55	B-56
O	O	O	0.1054	O	0.0384	O	O
B-57	B-58	B-59	B-60	B-61	B-62	B-63	B-64
O	O	O	O	O	O	O	O

Third layer: 24"-36"

B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
O	O	O	O	O	O	O	O
B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16
O	O	O	O	O	O	O	O
B-17	B-18	B-19	B-20	B-21	B-22	B-23	B-24
O	O	O	O	O	O	O	O
B-25	B-26	B-27	B-28	B-29	B-30	B-31	B-32
O	O	O	O	0.0514	0.0208	O	O
B-33	B-34	B-35	B-36	B-37	B-38	B-39	B-40
O	O	O	0.0484	O	O	O	O
B-41	B-42	B-43	B-44	B-45	B-46	B-47	B-48
O	O	O	O	O	O	O	O
B-49	B-50	B-51	B-52	B-53	B-54	B-55	B-56
O	O	O	O	O	O	O	O
B-57	B-58	B-59	B-60	B-61	B-62	B-63	B-64
O	O	O	O	O	O	O	O

Fourth layer: 36"-48"

B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
O	O	O	O	O	O	O	O
B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16
O	O	O	O	O	O	O	O
B-17	B-18	B-19	B-20	B-21	B-22	B-23	B-24
O	O	O	O	O	O	O	O
B-25	B-26	B-27	B-28	B-29	B-30	B-31	B-32
O	O	O	O	O	O	O	O
B-33	B-34	B-35	B-36	B-37	B-38	B-39	B-40
O	O	O	O	O	O	O	O
B-41	B-42	B-43	B-44	B-45	B-46	B-47	B-48
O	O	O	O	O	O	O	O
B-49	B-50	B-51	B-52	B-53	B-54	B-55	B-56
O	O	O	O	O	O	O	O
B-57	B-58	B-59	B-60	B-61	B-62	B-63	B-64
O	O	O	O	O	O	O	O

cc

B-12 = block number; 0.0274 = dry weight in grams of roots in one cubic foot of soil; ⊕ = location of tree trunk; O = blocks without roots.

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 1.

Text figure no. 3

Tree no. 2

First layer: 0'-12"

B-65	B-66	B-67	B-68	B-69	B-70	B-71	B-72
0	0	1.2058	0.7715	0.0318	0.0782	0.0118	0
B-73	B-74	B-75	B-76	B-77	B-78	B-79	B-80
0.2554	0.0766	0.0704	0.3506	0.4912	0.1732	0.0830	0.0174
B-81	B-82	B-83	B-84	B-85	B-86	B-87	B-88
0	0.0120	0.9102	5.5076	2.8816	0.8219	0.0816	0
B-89	B-90	B-91	B-92	B-93	B-94	B-95	B-96
0.0034	0.3116	3.7120	17.5400	2.8812	1.9848	0.3132	0
B-97	B-98	B-99	B-100 •	B-101	B-102	B-103	B-104
0	0	1.4412	192.54	28.67	2.3648	0	0
B-105	B-106	B-107	B-108	B-109	B-110	B-111	B-112
0	0	2.0811	8.1050	5.3400	2.2618	0.1986	0
B-113	B-114	B-115	B-116	B-117	B-118	B-119	B-120
0	0	0	2.5502	1.7314	0.1434	0	0
B-121	B-122	B-123	B-124	B-125	B-126	B-127	B-128
0	0	0	0.4678	0.3518	0	0	0

Second layer: 12'-24"

B-65	B-66	B-67	B-68	B-69	B-70	B-71	B-72
0	0	0	0	0	0	0	0
B-73	B-74	B-75	B-76	B-77	B-78	B-79	B-80
0	0	0	0.1012	0.1039	0	0	0
B-81	B-82	B-83	B-84	B-85	B-86	B-87	B-88
0	0	0	0.6870	0.3878	0.0834	0	0
B-89	B-90	B-91	B-92	B-93	B-94	B-95	B-96
0	0	0	0.1385	1.1808	0.1122	0	0
B-97	B-98	B-99	B-100 •	B-101	B-102	B-103	B-104
0	0	0.0770	3.3460	1.1478	0.1680	0	0
B-105	B-106	B-107	B-108	B-109	B-110	B-111	B-112
0	0	0.1230	1.1730	0.8062	0.3991	0.4188	0
B-113	B-114	B-115	B-116	B-117	B-118	B-119	B-120
0	0	0	0.2008	0.0456	0	0	0
B-121	B-122	B-123	B-124	B-125	B-126	B-127	B-128
0	0	0	0.0712	0	0	0	0

Third layer: 24'-36"

B-65	B-66	B-67	B-68	B-69	B-70	B-71	B-72
0	0	0	0	0	0	0	0
B-73	B-74	B-75	B-76	B-77	B-78	B-79	B-80
0	0	0	0	0	0	0	0
B-81	B-82	B-83	B-84	B-85	B-86	B-87	B-88
0	0	0.1008	0.0400	0	0	0	0
B-89	B-90	B-91	B-92	B-93	B-94	B-95	B-96
0	0	0	0	0	0	0	0
B-97	B-98	B-99	B-100 •	B-101	B-102	B-103	B-104
0	0	0	0.6730	0.1180	0	0	0
B-105	B-106	B-107	B-108	B-109	B-110	B-111	B-112
0	0	0	0	0.0254	0	0	0
B-113	B-114	B-115	B-116	B-117	B-118	B-119	B-120
0	0	0	0	0	0	0	0
B-121	B-122	B-123	B-124	B-125	B-126	B-127	B-128
0	0	0	0	0	0	0	0

Fourth layer: 36'-48"

B-65	B-66	B-67	B-68	B-69	B-70	B-71	B-72
0	0	0	0	0	0	0	0
B-73	B-74	B-75	B-76	B-77	B-78	B-79	B-80
0	0	0	0	0	0	0	0
B-81	B-82	B-83	B-84	B-85	B-86	B-87	B-88
0	0	0	0	0	0	0	0
B-89	B-90	B-91	B-92	B-93	B-94	B-95	B-96
0	0	0	0	0	0	0	0
B-97	B-98	B-99	B-100	B-101	B-102	B-103	B-104
0	0	0	0	0	0	0	0
B-105	B-106	B-107	B-108	B-109	B-110	B-111	B-112
0	0	0	0	0	0	0	0
B-113	B-114	B-115	B-116	B-117	B-118	B-119	B-120
0	0	0	0	0	0	0	0
B-121	B-122	B-123	B-124	B-125	B-126	B-127	B-128
0	0	0	0	0	0	0	0

B-67 = block number; 1.2058 = dry weight in grams of roots in one cubic foot of soil;
• = location of tree trunk; 0 = blocks without roots.

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 2.

Text figure no. 4

Tree no 3

First layer: 0'-12'

B-129	B-130	B-131	B-132	B-133	B-134	B-135	B-136
O	O	O	0.5932	0.5557	0.0404	0.0518	0.4178
B-137	B-138	B-139	B-140	B-141	B-142	B-143	B-144
0.0027	O	0.0210	0.2148	0.1880	0.2777	0.2120	0.0012
B-145	B-146	B-147	B-148	B-149	B-150	B-151	B-152
0.0268	0.0077	O	0.3308	1.5159	2.9248	0.1297	0.1114
B-153	B-154	B-155	B-156	B-157	B-158	B-159	B-160
0.0710	0.8104	1.7128	1.2538	8.4284	7.4712	0.8512	0.0766
B-161	B-162	B-163	B-164	B-165	B-166	B-167	B-168
O	O	2.1461	106.52	4.8424	27.2188	O	0.0818
B-169	B-170	B-171	B-172	B-173	B-174	B-175	B-176
0.3512	0.1826	2.9066	9.1652	10.8920	3.1560	0.9246	O
B-177	B-178	B-179	B-180	B-181	B-182	B-183	B-184
O	O	0.4764	0.6548	1.4670	0.9746	0.2610	O
B-185	B-186	B-187	B-188	B-189	B-190	B-191	B-192
O	O	O	0.2461	0.1888	0.0156	O	O

Second layer: 12'-24'

B-129	B-130	B-131	B-132	B-133	B-134	B-135	B-136
O	O	O	O	O	O	O	O
B-137	B-138	B-139	B-140	B-141	B-142	B-143	B-144
O	O	O	0.1488	0.6322	O	O	O
B-145	B-146	B-147	B-148	B-149	B-150	B-151	B-152
O	O	O	O	0.2940	0.1214	O	O
B-153	B-154	B-155	B-156	B-157	B-158	B-159	B-160
O	O	0.2549	0.2134	0.2712	O	O	O
B-161	B-162	B-163	B-164	B-165	B-166	B-167	B-168
O	0.1138	0.8323	1.8119	2.2714	0.8820	O	O
B-169	B-170	B-171	B-172	B-173	B-174	B-175	B-176
O	0.2710	0.1824	1.4336	0.4230	0.5888	0.0706	O
B-177	B-178	B-179	B-180	B-181	B-182	B-183	B-184
O	O	O	0.8801	O	O	O	O
B-185	B-186	B-187	B-188	B-189	B-190	B-191	B-192
O	O	O	O	O	O	O	O

Third layer: 24'-36'

B-129	B-130	B-131	B-132	B-133	B-134	B-135	B-136
O	O	O	O	O	O	O	O
B-137	B-138	B-139	B-140	B-141	B-142	B-143	B-144
O	O	O	O	O	O	O	O
B-145	B-146	B-147	B-148	B-149	B-150	B-151	B-152
O	O	O	O	O	O	O	O
B-153	B-154	B-155	B-156	B-157	B-158	B-159	B-160
O	O	O	O	O	O	O	O
B-161	B-162	B-163	B-164	B-165	B-166	B-167	B-168
O	O	O	0.0185	0.0320	O	O	O
B-169	B-170	B-171	B-172	B-173	B-174	B-175	B-176
O	O	0.0474	0.0858	O	O	O	O
B-177	B-178	B-179	B-180	B-181	B-182	B-183	B-184
O	O	O	O	O	O	O	O
B-185	B-186	B-187	B-188	B-189	B-190	B-191	B-192
O	O	O	O	O	O	O	O

Fourth layer: 36'-48'

B-129	B-130	B-131	B-132	B-133	B-134	B-135	B-136
O	O	O	O	O	O	O	O
B-137	B-138	B-139	B-140	B-141	B-142	B-143	B-144
O	O	O	O	O	O	O	O
B-145	B-146	B-147	B-148	B-149	B-150	B-151	B-152
O	O	O	O	O	O	O	O
B-153	B-154	B-155	B-156	B-157	B-158	B-159	B-160
O	O	O	O	O	O	O	O
B-161	B-162	B-163	B-164	B-165	B-166	B-167	B-168
O	O	O	O	0.1208	0.3075	O	O
B-169	B-170	B-171	B-172	B-173	B-174	B-175	B-176
0.2238	O	O	O	O	O	O	O
B-177	B-178	B-179	B-180	B-181	B-182	B-183	B-184
O	O	O	O	O	O	O	O
B-185	B-186	B-187	B-188	B-189	B-190	B-191	B-192
O	O	O	O	O	O	O	O

B-132 = block number; 0.3132 = dry weight in grams of roots in one cubic foot of soil;
• = location of tree trunk; O = blocks without roots

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 3.

Text figure no 5

Tree no.4

First layer: 0"-12"

B-193	B-194	B-195	B-196	B-197	B-198	B-199	B-200
O	O	O	0.0023	O	O	O	O
B-201	B-202	B-203	B-204	B-205	B-206	B-207	B-208
0.0114	0.0112	O	O	O	O	O	O
B-209	B-210	B-211	B-212	B-213	B-214	B-215	B-216
O	O	1.0567	0.0442	0.0400	O	O	O
B-217	B-218	B-219	B-220	B-221	B-222	B-223	B-224
O	0.3818	2.0376	0.1924	0.2098	0.4158	O	O
B-225	B-226	B-227	B-228	B-229	B-230	B-231	B-232
O	0.0824	4.0136	72.1130	2.6314	0.5014	O	O
B-233	B-234	B-235	B-236	B-237	B-238	B-239	B-240
O	0.2442	18.5546	2.6894	3.1380	0.8120	0.0138	O
B-241	B-242	B-243	B-244	B-245	B-246	B-247	B-248
O	0.2250	0.8240	0.6428	2.1268	0.1830	O	O
B-249	B-250	B-251	B-252	B-253	B-254	B-255	B-256
O	O	O	0.0670	0.4037	0.9352	0.2280	

Second layer: 12"-24"

B-193	B-194	B-195	B-196	B-197	B-198	B-199	B-200
O	O	O	O	O	O	O	O
B-201	B-202	B-203	B-204	B-205	B-206	B-207	B-208
O	O	O	O	O	O	O	O
B-209	B-210	B-211	B-212	B-213	B-214	B-215	B-216
O	O	O	O	O	O	O	O
B-217	B-218	B-219	B-220	B-221	B-222	B-223	B-224
O	O	0.1148	0.0586	0.0537	O	O	O
B-225	B-226	B-227	B-228	B-229	B-230	B-231	B-232
O	O	0.0112	3.7660	O	0.5912	O	O
B-233	B-234	B-235	B-236	B-237	B-238	B-239	B-240
O	O	0.0464	0.3108	0.3282	0.1810	0.0346	O
B-241	B-242	B-243	B-244	B-245	B-246	B-247	B-248
O	O	O	O	0.3236	O	O	O
B-249	B-250	B-251	B-252	B-253	B-254	B-255	B-256
O	O	O	O	O	O	O	O

Third layer: 24"-36"

B-193	B-194	B-195	B-196	B-197	B-198	B-199	B-200
O	O	O	O	O	O	O	O
B-201	B-202	B-203	B-204	B-205	B-206	B-207	B-208
O	O	O	O	O	O	O	O
B-209	B-210	B-211	B-212	B-213	B-214	B-215	B-216
O	O	O	O	O	0.1206	O	O
B-217	B-218	B-219	B-220	B-221	B-222	B-223	B-224
O	O	O	O	O	O	O	O
B-225	B-226	B-227	B-228	B-229	B-230	B-231	B-232
O	O	0.0700	0.2616	O	O	O	O
B-233	B-234	B-235	B-236	B-237	B-238	B-239	B-240
O	O	0.0574	0.1184	0.0110	0.0230	O	O
B-241	B-242	B-243	B-244	B-245	B-246	B-247	B-248
O	O	O	O	O	O	O	O
B-249	B-250	B-251	B-252	B-253	B-254	B-255	B-256
O	O	O	O	O	O	O	O

Fourth layer: 36"-48"

B-193	B-194	B-195	B-196	B-197	B-198	B-199	B-200
O	O	O	O	O	O	O	O
B-201	B-202	B-203	B-204	B-205	B-206	B-207	B-208
O	O	O	O	O	O	O	O
B-209	B-210	B-211	B-212	B-213	B-214	B-215	B-216
O	O	O	O	O	O	O	O
B-217	B-218	B-219	B-220	B-221	B-222	B-223	B-224
O	O	O	O	O	O	O	O
B-225	B-226	B-227	B-228	B-229	B-230	B-231	B-232
O	O	O	O	O	O	O	O
B-233	B-234	B-235	B-236	B-237	B-238	B-239	B-240
O	O	O	O	O	O	O	O
B-241	B-242	B-243	B-244	B-245	B-246	B-247	B-248
O	O	O	O	O	O	O	O
B-249	B-250	B-251	B-252	B-253	B-254	B-255	B-256
O	O	O	O	O	O	O	O

B-196 = block number; 0.0023 = dry weight in grams of roots in one cubic foot of soil;
⊕ = location of tree trunk; O = blocks without roots

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 4.

Text figure no.6

Tree no5

First layer: 0"-12"

B-257	B-258	B-259	B-260	B-261	B-262	B-263	B-264
O	O	0.0444	0.0148	O	0.0138	0.0074	0.0064
B-265	B-266	B-267	B-268	B-269	B-270	B-271	B-272
0.0296	0.0238	0.0447	O	0.0036	0.0464	0.0214	O
B-273	B-274	B-275	B-276	B-277	B-278	B-279	B-280
0.1132	0.1060	O	0.0712	0.7319	O	O	O
B-281	B-282	B-283	B-284	B-285	B-286	B-287	B-288
O	0.3820	0.8950	0.3619	0.4776	2.4616	0.1084	O
B-289	B-290	B-291	B-292	B-293	B-294	B-295	B-296
0.7136	0.9804	2.0512	1.9846	4.1830	4.6529	0.6710	O
B-297	B-298	B-299	B-300	B-301	B-302	B-303	B-304
1.0338	1.8522	8.4340	73.9154	29.2916	3.2820	O	O
B-305	B-306	B-307	B-308	B-309	B-310	B-311	B-312
1.6272	2.4931	0.9932	5.4614	8.0780	2.9224	0.1464	0.4834
B-313	B-314	B-315	B-316	B-317	B-318	B-319	B-320
O	1.1518	0.6680	0.2566	3.4512	4.0812	1.6464	0.3170

Second layer: 12"-24"

B-257	B-258	B-259	B-260	B-261	B-262	B-263	B-264
O	O	O	O	O	O	O	O
B-265	B-266	B-267	B-268	B-269	B-270	B-271	B-272
O	O	O	O	O	O	O	O
B-273	B-274	B-275	B-276	B-277	B-278	B-279	B-280
O	O	O	O	O	0.1668	O	O
B-281	B-282	B-283	B-284	B-285	B-286	B-287	B-288
O	O	O	0.0128	0.5146	0.0112	0.0801	0.1032
B-289	B-290	B-291	B-292	B-293	B-294	B-295	B-296
O	O	0.1250	2.5664	0.8100	0.2102	O	O
B-297	B-298	B-299	B-300	B-301	B-302	B-303	B-304
O	O	0.3188	5.3712	1.5020	O	0.3116	O
B-305	B-306	B-307	B-308	B-309	B-310	B-311	B-312
O	O	0.1104	0.7844	0.8648	0.4148	0.0761	O
B-313	B-314	B-315	B-316	B-317	B-318	B-319	B-320
O	O	O	O	0.1938	0.3762	0.2124	O

Third layer: 24"-36"

B-257	B-258	B-259	B-260	B-261	B-262	B-263	B-264
O	O	O	O	O	O	O	O
B-265	B-266	B-267	B-268	B-269	B-270	B-271	B-272
O	O	O	O	O	O	O	O
B-273	B-274	B-275	B-276	B-277	B-278	B-279	B-280
O	O	O	O	O	O	O	O
B-281	B-282	B-283	B-284	B-285	B-286	B-287	B-288
O	O	O	O	O	O	O	O
B-289	B-290	B-291	B-292	B-293	B-294	B-295	B-296
O	O	O	0.0500	0.2154	O	O	O
B-297	B-298	B-299	B-300	B-301	B-302	B-303	B-304
O	O	0.1242	0.1462	0.3220	O	O	O
B-305	B-306	B-307	B-308	B-309	B-310	B-311	B-312
O	O	O	O	O	O	O	O
B-313	B-314	B-315	B-316	B-317	B-318	B-319	B-320
O	O	O	O	O	O	O	O

Fourth layer: 36"-48"

B-257	B-258	B-259	B-260	B-261	B-262	B-263	B-264
O	O	O	O	O	O	O	O
B-265	B-266	B-267	B-268	B-269	B-270	B-271	B-272
O	O	O	O	O	O	O	O
B-273	B-274	B-275	B-276	B-277	B-278	B-279	B-280
O	O	O	O	O	O	O	O
B-281	B-282	B-283	B-284	B-285	B-286	B-287	B-288
O	O	O	O	O	O	O	O
B-289	B-290	B-291	B-292	B-293	B-294	B-295	B-296
O	O	O	O	O	O	O	O
B-297	B-298	B-299	B-300	B-301	B-302	B-303	B-304
O	O	O	O	O	O	O	O
B-305	B-306	B-307	B-308	B-309	B-310	B-311	B-312
O	O	O	O	O	O	O	O
B-313	B-314	B-315	B-316	B-317	B-318	B-319	B 320
O	O	O	O	O	O	O	O

B-259 = block number; 0.0444 = dry weight in grams of roots in one cubic foot of soil;
• = location of tree trunk; O = blocks without roots

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 5.

Text figure no.7

Tree no8

First layer: 0"-12"

B-321 O	B-322 O	B-323 0.0018	B-324 0.0078	B-325 0.6194	B-326 0.1392	B-327 0.0160	B-328 0.0315
B-329 O	B-330 O	B-331 O	B-332 O	B-333 O	B-334 0.8162	B-335 0.0082	B-336 O
B-337 O	B-338 O	B-339 O	B-340 O	B-341 O	B-342 O	B-343 O	B-344 O
B-345 O	B-346 O	B-347 O	B-348 0.3830	B-349 1.2182	B-350 0.3182	B-351 O	B-352 O
B-353 0.1656	B-354 1.2126	B-355 0.3616	B-356 8.7869	B-357 3.2454	B-358 0.4760	B-359 0.7916	B-360 O
B-361 0.0706	B-362 2.5303	B-363 3.6772	B-364 82.53	B-365 84.90	B-366 6.4219	B-367 1.3718	B-368 O
B-369 O	B-370 O	B-371 1.3388	B-372 9.3220	B-373 9.4508	B-374 5.3474	B-375 0.1358	B-376 O
B-377 0.1944	B-378 O	B-379 O	B-380 2.5128	B-381 0.1028	B-382 0.8616	B-383 O	B-384 O

Second layer: 12"-24"

B-321 O	B-322 O	B-323 O	B-324 O	B-325 O	B-326 O	B-327 O	B-328 O
B-329 O	B-330 O	B-331 O	B-332 O	B-333 O	B-334 O	B-335 O	B-336 O
B-337 O	B-338 O	B-339 O	B-340 O	B-341 O	B-342 O	B-343 O	B-344 O
B-345 O	B-346 O	B-347 O	B-348 O	B-349 O	B-350 O	B-351 O	B-352 O
B-353 0.2312	B-354 O	B-355 O	B-356 0.1801	B-357 0.5814	B-358 0.1126	B-359 O	B-360 O
B-361 O	B-362 O	B-363 1.0916	B-364 5.5681	B-365 5.7730	B-366 0.1908	B-367 O	B-368 O
B-369 O	B-370 O	B-371 O	B-372 1.0802	B-373 2.2860	B-374 0.0836	B-375 O	B-376 O
B-377 O	B-378 O	B-379 O	B-380 O	B-381 O	B-382 O	B-383 O	B-384 O

Third layer: 24"-36"

B-321 O	B-322 O	B-323 O	B-324 O	B-325 O	B-326 O	B-327 O	B-328 O
B-329 O	B-330 O	B-331 O	B-332 O	B-333 O	B-334 O	B-335 O	B-336 O
B-337 O	B-338 O	B-339 O	B-340 O	B-341 O	B-342 O	B-343 O	B-344 O
B-345 O	B-346 O	B-347 O	B-348 O	B-349 O	B-350 O	B-351 O	B-352 O
B-353 O	B-354 O	B-355 O	B-356 0.1078	B-357 0.1207	B-358 0.1908	B-359 O	B-360 O
B-361 O	B-362 O	B-363 0.0262	B-364 1.3864	B-365 1.3946	B-366 0.2040	B-367 O	B-368 O
B-369 O	B-370 O	B-371 0.5400	B-372 1.1872	B-373 0.2168	B-374 O	B-375 O	B-376 O
B-377 O	B-378 O	B-379 O	B-380 O	B-381 0.0159	B-382 O	B-383 O	B-384 O

Fourth layer: 36"-48"

B-321 O	B-322 O	B-323 O	B-324 O	B-325 O	B-326 O	B-327 O	B-328 O
B-329 O	B-330 O	B-331 O	B-332 O	B-333 O	B-334 O	B-335 O	B-336 O
B-337 O	B-338 O	B-339 O	B-340 O	B-341 O	B-342 O	B-343 O	B-344 O
B-345 O	B-346 O	B-347 O	B-348 O	B-349 O	B-350 O	B-351 O	B-352 O
B-353 O	B-354 O	B-355 O	B-356 O	B-357 O	B-358 O	B-359 O	B-360 O
B-361 O	B-362 O	B-363 O	B-364 O	B-365 0.0154	B-366 O	B-367 O	B-368 O
B-369 O	B-370 O	B-371 O	B-372 O	B-373 O	B-374 O	B-375 O	B-376 O
B-377 O	B-378 O	B-379 O	B-380 O	B-381 O	B-382 O	B-383 O	B-384 O

B-323= block number; 0.0018= dry weight in grams of roots in one cubic foot of soil;
●= location of tree trunk; O= blocks without roots.

Diagram indicating dry weight of roots per cubic foot of soil excavated in each layer of tree 8.

Text figure no.8

As to planting system, the coffee seedlings should never be buried in the planting holes at time of planting. There is a tendency in the farmers to plant too deep which results in the tender new roots have to penetrate in hard, less fertile layers of soil affecting tremendously the rate and total amount of growth of the whole tree. The seedlings should be planted at the same level as that of the plants in the nursery, in this way all the good soil characteristics of the surface layers give the young seedlings better chances for a strong, vigorous development.

However, the root systems should be gradually induced to penetrate to deeper soil depths so that the roots may resist prolonged droughts, and absorb nutrients when the surface layers begin to get short of water and plant foods. This may be accomplished by making deep holes half way between the rows of trees in which to apply vegetable manures and chemical fertilizers. Such holes would in addition serve as deposits for fallen leaves and other plant débris.

In performing general agricultural operations, care should be taken to prune and mutilate the least number of roots by using proper tools and not operating too close to the tree trunks. This is possible by cultivating only in narrow strips half-way between the rows of trees. Recently vertical forks have been used successfully by numerous farmers because of their adaptability to loosen the soil breaking the least number of roots.

The coffee seedlings is susceptible to stagnant water, therefore, in soils with imperfect drainage, drainage ditchs should be provided in order to dispose of the excessive moisture.

The greatest concentration of roots being found at the top-most soil layer, fertilizer applications need not to be applied too deep. It is recommended to loosen the soil slightly under the drip of the trees and mix the fertilizer applied with the top soil and mulch. But on steep soils the fertilizer must be applied on the individual terraces or in shallow pits dug-out at the trunks in order to avoid washing of the fertilizer during heavy rainfall.

The better aeration of the surface layer is responsible to a certain extent for the greatest concentration of roots at the top-most 12 inches, therefore the soil of coffee plantations should be loosened to improve the aeration and consequently promote all the physical, chemical and biologic processes necssary for optimum root growth.

Summary

1. The various methods used by Gómez (1) Lee (2) Lee and Bissinger (3), Nutman (4), (5), (6), Trench (7), Venkatraman (8), and Weaver and his associated (9), (10) for the study of the root system of plants have been described and discussed fully.

2. A new method developed by the writers has been described and used for the study of the root system of coffee, *C. arabica* L. in Puerto Rico. Briefly, this method consists in excavating the volume of soil assigned to each tree under study by blocks of one-cubic foot each and separating, drying and weighing the roots obtained from each block. By keeping an excavation map for the root system of the trees, the exact position of roots obtained for each block is obtained, therefore being possible to determine the quantity of roots present at the various soil levels excavated and the lateral spread of the roots as well.

3. Ninety-four percent of the coffee roots of all trees were found in the top-most 12 inches of soil.

4. The high percentage of organic matter in Coloso Clay, especially in the top-most layers, and the better aeration at the surface, apparently accounted to a great extent for the presence of more roots in the top-most 12 inches of soil.

5. The imperfect drainage conditions existing at localities where Coloso Clay predominates affect the development of the root systems of coffee plants.

6. Coloso Clay is a productive soil when proper drainage conditions are provided and the principal plant foods are generally distributed uniformly to a depth of 48 inches.

7. A heavy and vigorous coffee tree top is not dependent on an extensive root system.

8. There is no fixed "(tops to roots) ratio" in coffee trees, but generally the ratio of tops to roots may be figured to be 8:1.

9. In selecting trees with vigorous, heavy tops and a strong, extensive root systems, the diameter of the trunk is a better indication of the possession of these characteristics than either the height or the lateral spread of the tree.

10. There was approximately 50 percent of water in the upright stems of coffee trees, 23 percent in the lateral branches and leaves, 39 percent in the whole tree tops and 50 percent in the roots.

11. The absorbing area of the root system is not confined to definite places on the soil but is distributed thru-out all places penetrated by the main and secondary roots.

12. The vertical penetration of roots of 7-year-old trees is 3 feet and the lateral extension is 4 feet.

13. The results obtained have been discussed fully in relation to possible aplications in the performance of agricultural practices followed by farmers in coffee plantations.

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